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TECHNICAL MEMORANDUM 97/216
August 1997

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Abstract

This report gives results of an extensive validation of DND's strip theory program SHIPMO7 and the three-dimensional ship motion code PRECAL developed by Cooperative Research Ships. Ship motion and sea load predictions are compared with results for the CPF hydroelastic model, which was tested in regular and irregular waves in both head and oblique seas. In general, both codes give excellent agreement for ship motions and reasonable agreement for sea loads. In irregular head seas, PRECAL overpredicts vertical bending moment at midships by an average of 9 percent, which is superior to the average overprediction by SHIPMO7 of 25 percent.

Résumé

Le présent rapport présent une validation complète du programme de théorie des bandes SHIPMO7 et du code PRECAL des mouvements de navires en trois dimensions du MDN, développés par les navires de recherche coopérative. Les prédictions des mouvements des navires et des charges de mer sont comparées aux résultats du modèle hydroélastique FCP qui a été mis à l'essai dans des vagues régulières et irrégulières venant de l'avant et en oblique. En général, les deux codes ont un rapport de concordance excellent avec les mouvements des navires et un rapport de concordance raisonnable avec les charges de mer. Pour la houle avant irrégulière, PRECAL surestime le moment de flexion verticale au milieu du navire de 9 p. 100 en moyenne, ce qui est supérieur à la surestimation moyenne de 25 p. 100 par SHIPMO7.

DREA TM/97/216

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EXECUTIVE SUMMARY

Introduction

Predictions of ship motions and sea loads in waves are required for rational ship design and maintenance. This study compares results from two seakeeping codes with model test data for the Canadian Patrol Frigate (CPF). The first code is DND's strip theory program SHIPMO7, and the second code is PRECAL, a three-dimensional program developed by the Cooperative Research Ships organization. Both codes are being considered for ongoing support of ship maintenance for the CPF. The model tests were carried out at the Institute for Marine Dynamics, and consist of ship motions and sea loads experiments in regular and oblique seas for both head and oblique sea directions. While the majority of experimental results for the CPF hydroelastic model are proprietary to DND, this report includes a selection of plots used in the validation study.

Principal Results

In general, SHIPMO7 and PRECAL give excellent agreement with experimental results for ship motions and reasonable agreement for sea loads, with PRECAL giving the better results. For vertical bending moment at midships in irregular head seas, PRECAL overpredicts experimental values by 3 percent at low speed, increasing to 15 percent at high speed. SHIPMO7 consistently overpredicts vertical bending moment at midships by approximately 25 percent, with little dependence on speed.

Both SHIPMO7 and PRECAL give relatively poor torsion predictions. PRECAL incorrectly assumes constant metacentric height along the length of the ship. Although SHIPMO7 correctly considers the longitudinal variation of sectional metacentric height, the geometry of the CPF combined with the limitations of strip theory likely cause poor torsion predictions. Another source of errors for torsion predictions is that the roll gyradii of the model segments are unknown.

Experimental measurements of vertical bending moments and shear forces in irregular head seas show that vertical loads are almost identical for the operational light and deep departure loading conditions.

Significance of Results

The superior load predictions of PRECAL over SHIPMO7 indicate that the transom stern of the CPF causes three-dimensional effects to be significant. At high forward speed, the accuracy of PRECAL deteriorates, likely due to assumptions related to the zero speed Green function and to neglect of the steady speed diffraction potential.

The consistency of the experimental results suggests that the model test data are generally reliable. Uncertainty remains regarding roll inertia properties of the CPF hydroelastic model during the IMD tests; thus, the present torsion experimental data must be used with caution. Given that lateral plane loads are small relative to vertical plane loads for the CPF, the uncertainty of the segment roll inertia properties does not significantly affect the overall usefulness of the IMD data.

The very close agreement of vertical plane sea loads for the deep departure and operational light loading conditions indicates that sea loads for a representative loading condition can be applied to a range of loading conditions. This result could significantly reduce the amount of computational work required for future analysis in support of CPF maintenance.

When selecting a code for motion and sea load analysis, the relative merits of both codes must be considered. PRECAL's three-dimensional theory gives better vertical plane load predictions. For lateral plane motions and sea loads, SHIPMO7 has the advantages of good roll damping predictions and correct treatment of the longitudinal variation of sectional metacentric height for torsion computations. For general predictions of ship motions and sea loads, SHIPMO7 can provide comprehensive results for both vertical and lateral modes. PRECAL is recommended for cases requiring hydrodynamic pressures on the hull or more accurate vertical plane loads.

Future Plans

Because of the importance of three-dimensional effects for the CPF, DREA will continue to monitor new developments with PRECAL. PRECAL has good potential for better predictions through improvements in the areas of roll damping, forward speed Green function, and sectional roll restoring forces.

In support of future maintenance, a database of CPF motions and sea loads in waves will be developed. The present results suggest that the database will only require a single operational load condition. An important initial task will be evaluation of the actual mass distribution for the CPF. The database will then be generated using the most suitable code for predicting ship motions and sea loads. Updates to the database will be made as more accurate prediction tools become available.

Contents

Notation

a	wave amplitude
AP	aft perpendicular
B	beam
C_B	block coefficient
FP	forward perpendicular
Fn	Froude number
$\overline{GM}$	metacentric height
g	gravitational acceleration
H	wave height
H_s	significant wave height
k	wavenumber
$\overline{KG}$	vertical height of centre of gravity above baseline
L	ship length between forward and aft perpendiculars
LCG	longitudinal location of centre of gravity (aft of midships)
$LCGFP$	longitudinal location of centre of gravity (aft of FP)
m	mean
n_4	number of roll cycles
T	period of oscillation or draft
T_p	peak wave period
T_z	zero-crossing period
T_0	modal wave period
T_4	natural roll period
U	mean forward ship speed
V_i	amplitude of load component i
β_s	incident sea direction (relative to ship speed)
ζ_i	motion amplitude for mode i
λ	wavelength or linear model scaling factor
ξ_4	roll damping coefficient
ρ	water density
σ	standard deviation
σ_ϕ	RMS roll displacement
$\hat{\phi}$	initial roll displacement
ω	wave frequency
ω_e	encounter frequency
Δ	ship mass displacement

1 Introduction

Predictions of ship motions and sea loads are essential elements of ship design and maintenance. This report describes a validation study of the ship motions and sea loads of the Canadian Patrol Frigate (CPF) hydroelastic model predicted by two codes, SHIPMO7 and PRECAL. Another validation study [1] compares SHIPMO7 and PRECAL predictions with data for the warship model of Lloyd et al. [2, 3].

SHIPMO7 is an updated version of DREA's ship motion code SHIPMO [4], a strip theory program for evaluating seakeeping of slender ships in moderate seas. PRECAL is a suite of programs developed by the Cooperative Research Ships (CRS) PRECAL Working Group and is based on three-dimensional panel theory. Both programs are designed to predict ship motions in regular waves, and in uni-directional and multi-directional irregular seas.

Reference 5 gives an overview of the CPF hydroelastic model experiments and some comparisons with SHIPMO7 and PRECAL. The 1:20 scale model of the CPF was built by Fleet Technology Limited and was tested by the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland. Reference 6 describes construction of the model and gives a detailed description of the model properties. The models tests were conducted in both regular and irregular waves with head and bow seas.

Previous SHIPMO versions have shown good agreement with experimental data for ship motions, but have not been as accurate in predicting sea loads [7, 8]. Validations of previous versions of PRECAL demonstrate a similar trend [9, 10]. PRECAL ship motion predictions demonstrated good agreement with experimental results, yet its sea load predictions were not significantly better than those from two-dimensional codes. Serious problems were also discovered with the roll motion prediction capabilities of PRECAL.

This study also includes some predictions from the time domain code MOSOLV [11, 12], which was developed for DREA by Aerospace Engineering and Research Consultants Limited (AERCOL). MOSOLV results are presented for only a small number of test cases because of generally poor agreement with experimental results and with the two frequency domain codes.

This report begins with descriptions of SHIPMO7 and PRECAL and their capabilities. MOSOLV is also briefly described. Section 5 discusses preparation of input files for the CPF. The hydroelastic model of the CPF and the tests conducted by IMD are subsequently described in Section 6. The report then presents comparisons of the model tests with numerical predictions in Section 7. A subsequent discussion in Section 8 highlights areas of good agreement and areas of deficiencies for the numerical predictions. Section 9 considers possible sources of discrepancies between predictions and experiments, and initiates further examination of numerical torsion predictions in Section 10. In Section 11, an error analysis of predicted motions and sea loads in irregular head seas gives practical insight for application of numerical predictions to design cases for the CPF. Section 12 examines sea loads in head seas for the operational light and deep departure loading conditions. The report finishes with general conclusions.

2 SHIPMO7 Strip Theory Program

SHIPMO7 [4] is the newest version of DREA's ship motion program SHIPMO, a strip theory program that is suitable for evaluating seakeeping of slender ships in moderate seas. Because of

its simple user input requirements and relatively fast computational time, SHIPMO7 is widely used for seakeeping analysis.

SHIPMO7 is a frequency domain code, based on the strip theory of Salvesen, Tuck and Faltinsen [13]. SHIPMO includes extensions first proposed by Schmitke [14] to include appendage forces and viscous roll damping forces. Graham [15] introduced further improvements to roll damping predictions. The most important update for SHIPMO7 is computation of sea loads including appendage and viscous forces. Other enhancements include elimination of irregular frequencies and prediction of added resistance in waves.

3 PRECAL Program Suite

PRECAL is a set of codes for predicting ship motions and sea loads of displacement hull vessels. The programs were developed through three Cooperative Research Ships (CRS) Working Groups. PRECAL is based on three-dimensional panel theory rather than the two-dimensional strip theory of SHIPMO7. It was expected that PRECAL predictions for sea loads would demonstrate better agreement with experimental results than SHIPMO7. Further discussion of PRECAL's theoretical basis and code design can be found in References 16 and 17.

The version of PRECAL used in this study (Version 1.0) has problems with predicting roll damping correctly. In this study, roll damping coefficients obtained from SHIPMO7 are input to PRECAL.

For irregular waves, PRECAL requires each ship speed to be run separately to obtain consistent results. This limitation is not noted in the PRECAL user's manual [16]. Initial load predictions in irregular waves were incorrect due to a bug in subroutine RDRAO of the program RESCAL. This bug was corrected and the resulting sea load predictions in irregular waves are included in this report.

In order to make comparisons with the experimental data, all SHIPMO7 and PRECAL RAO values were non-dimensionalized to a common format. For irregular waves, results from the prediction codes were converted to full-scale dimensional values.

4 MOSOLV Time Domain Suite

The time domain suite MOSOLV was developed by AERCOL under contract to DREA [11, 12, 18, 19]. The programs, which are based largely on the theory of Reference 20, use a time domain Green function and impulse response method to predict hydrodynamic forces. This approach was developed because of its potential for modelling forward speed effects, three-dimensional effects, and nonlinearities.

The MOSOLV program suite consists of the following three modules:

- STATEQ: calculates equilibrium hydrostatic conditions,
- IMPRSP: determines the radiation and diffraction hydrodynamic impulse response functions,
- MOSOLV: solves the hydrodynamic response equations for ship motions and resulting sea loads in the time domain.

The MOSOLV suite is limited to solving vertical plane motions and sea loads in head and following seas only. The code IMPRSP requires very large amounts of CPU time and memory for computing the hydrodynamic impulse response functions, and its computed impulse response functions are very prone to numerical instabilities. Given the problems with the MOSOLV suite and that AERCOL has not maintained expertise in this area, DREA plans no further development of the suite.

5 Prediction Code Input Parameters

Sample input files are given in Appendix A for SHIPMO7 and in Appendix B for PRECAL. It is essential that the input parameters describing the CPF hydroelastic model be correct. For sea load predictions, particular attention must be given to the ship mass distribution. For input into the prediction codes, sectional masses supplied by IMD were combined such that masses are assumed to be uniformly distributed between mid-stations (e.g. between stations 0.5 and 1.5). Provisions for bow and stern overhang masses are also available in the codes. The resulting sectional mass distributions for the CPF hydroelastic model are shown in Figures 1 and 2.

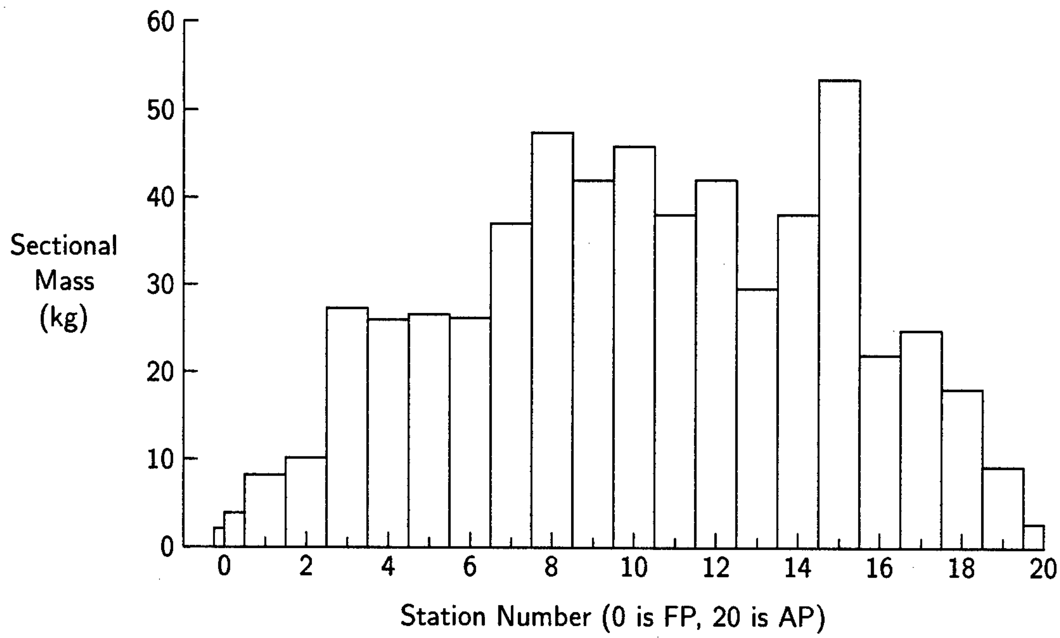

Figure 1: Input Sectional Mass Distribution for Deep Departure Condition

For the operational light condition, the longitudinal center of gravity location for segment 1 (nearest the bow) based on the estimated mass distribution was found to be significantly different from the value reported by IMD. In order to alleviate this problem, the sectional masses near the bow were redistributed so that the total segment mass and the longitudinal center of gravity of the segment approach the reported values. The results of the redistribution are shown in Table 1. Figure 2 shows the redistributed sectional mass distribution at the bow for the operational light condition.

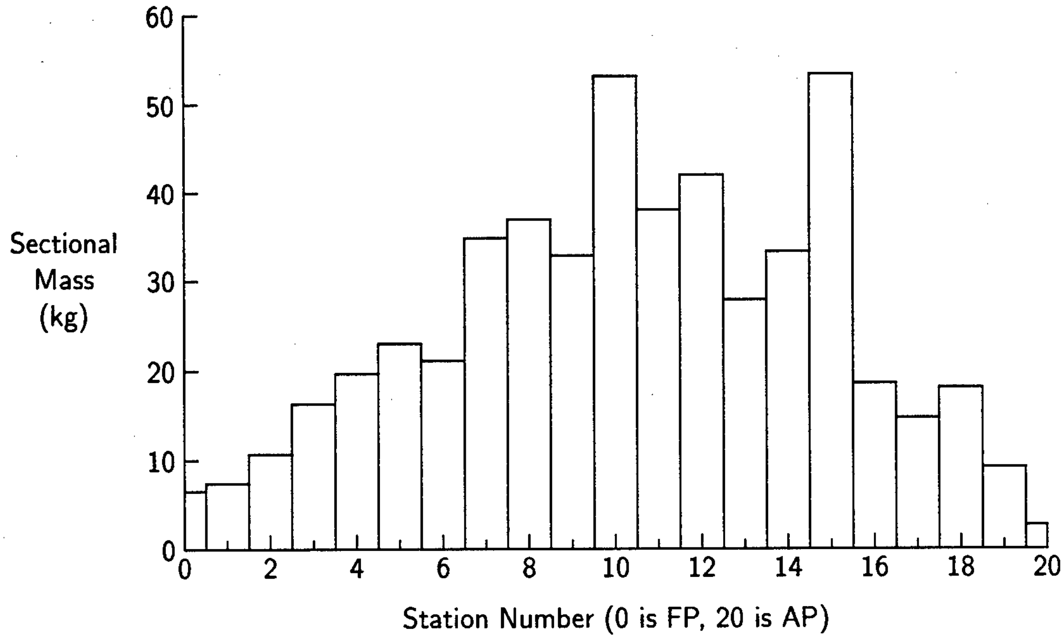

Figure 2: Input Sectional Mass Distribution for Operational Light Condition

Table 1: Mass Distributions for Model Segment 1, Operational Light Condition

	IMD Segment Values	**IMD Sectional Values**	**SHIPMO7 Input**
Bow overhang mass (kg)	—	3.402	0
Station 0 mass (kg)	—	3.853	6.635
Station 1 mass (kg)	—	8.231	7.500
Station 2 mass (kg)	—	10.155	10.715
Total Segment Mass (kg)	24.85	25.64	24.85
Segment LCGFP (mm)	362.4	326.0	383.4

Figures 3 and 4 show the segment mass distributions for the deep departure and operational light conditions, respectively. For both loading conditions, good agreement exists between segment properties reported by IMD and those based on the sectional mass distributions.

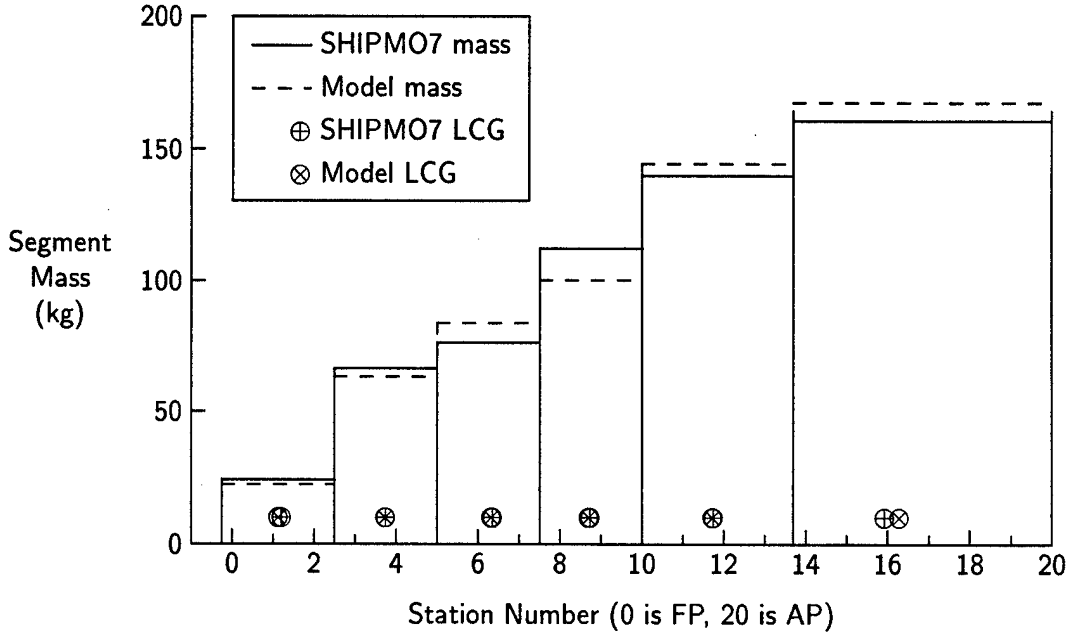

Figure 3: Model Segment Mass Distribution for Deep Departure Condition

For consistent load computations, the mass and longitudinal center of gravity location calculated from hydrostatics must match those of the mass distribution. Although the trim conditions calculated by SHIPMO7 and PRECAL did not match those of the experiments, correct modelling is more important for the mass distribution than for the trim condition, which can vary slightly without significantly affecting results. Thus the midships draft and trim by stern are adjusted such that the displacement and longitudinal center of gravity location from the ship hydrostatics match the values from the mass distribution.

To represent the roll properties of the hydroelastic model accurately, sectional roll inertia terms are required. Because oblique seas tests were conducted only for the deep departure condition, roll properties given here are only for that condition. SHIPMO7 requires roll gyradii to be input and PRECAL requires roll inertia. These input parameters were estimated using the roll gyradius given by IMD for the entire model. The resulting dry roll gyradius combined with an input roll metacentric height of 1.08 m allows SHIPMO7 to match the natural roll period of 12.3 s full-scale given by IMD; however, this dry roll gyradius gives a slightly lower roll period of 11.8 s from PRECAL due to differences between SHIPMO7 and PRECAL roll added masses. The procedure described in Reference 1 was used to determine the sectional roll inertia properties. This method provides reasonable estimates of the sectional properties which are consistent with the inertia properties of the entire model. These calculations were performed for each of the two weight conditions.

Initial SHIPMO7 roll predictions in oblique seas were significantly higher than experimental values at wave encounter frequencies near the ship roll natural frequency. This discrepancy was

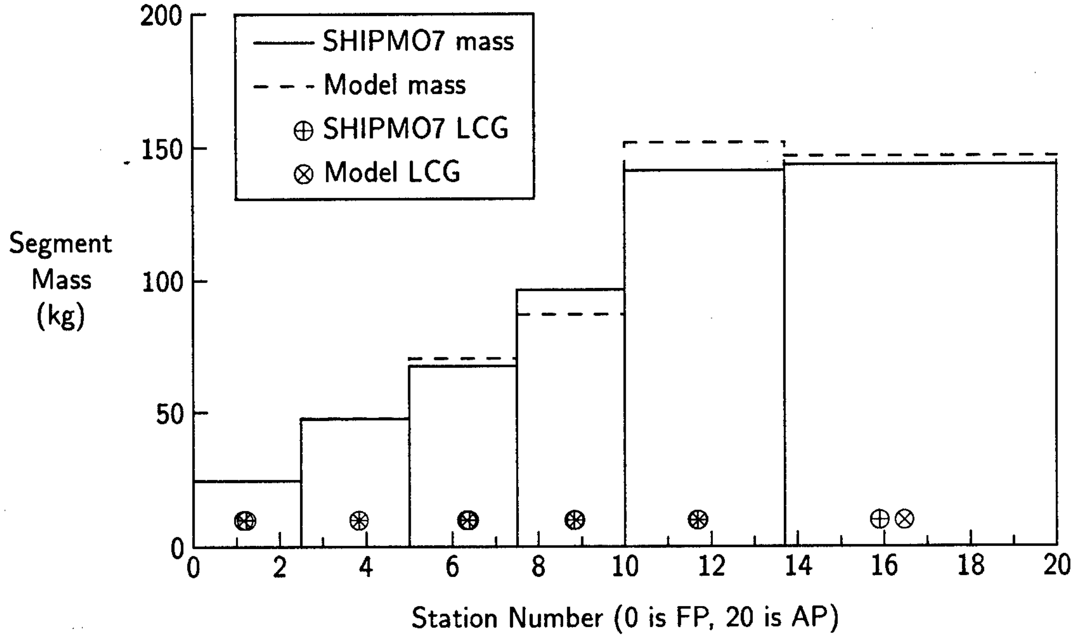

Figure 4: Model Segment Mass Distribution for Operational Light Condition

alleviated by increasing the SHIPMO7 input $\overline{KG}$ value for the deep departure condition from the reported value of 6.26 m to 6.50 m full scale, which allowed the metacentric height computed by SHIPMO7 to agree with the value of 1.08 m reported by IMD. Although the reported $\overline{GM}$ value of 1.08 m had initially been used as input to SHIPMO7, the revised $\overline{KG}$ value leads to improved roll predictions because of the sensitivity of roll excitation forces to vertical centre of gravity location. To maintain consistency with the revised $\overline{KG}$ value, all sectional $\overline{KG}$ values were increased by 0.24 m full scale. Unlike SHIPMO7, PRECAL appears to include the influence of a user input metacentric height on roll excitation forces; thus, $\overline{KG}$ values input to PRECAL were not modified.

When running PRECAL, the number of facets for computations must be selected carefully, with consideration for computational requirements and accuracy. The present study uses 160 facets on one side of the hull.

As mentioned earlier, the version of PRECAL used in this study has deficiencies with roll damping calculations. For each ship speed and heading, the SHIPMO7 roll damping at a wave encounter frequency near the ship roll natural frequency was used as input to PRECAL. The selection of a single damping coefficient for all wave frequencies was considered acceptable because roll damping is most important near resonance and because roll damping exhibits relatively little variation with wave frequency. For regular seas, SHIPMO7 roll damping coefficients for a wave steepness of 1/30 were used. For irregular seas, roll damping coefficients were taken for a Bretschneider spectrum with significant wave height of 5 m and peak wave period of 11 s. Tables 2 and 3 show damping coefficient values from SHIPMO7 used as input to PRECAL.

Unpublished results of roll decay tests obtained from IMD were used to estimate roll damping coefficients at zero speed. For a time series of lightly damped roll motions, the following equation

Table 2: Regular Wave Roll Damping Coefficients

Froude number	Sea direction β_s (degrees)		
Fn	135	165	180
0.06	0.135	0.108	0.050
0.12	0.147	0.119	0.050
0.20	0.162	0.132	0.050
0.25	0.171	0.141	0.050

Table 3: Irregular Wave Roll Damping Coefficients

Froude number	Sea direction β_s (degrees)			
Fn	135	150	165	180
0.06	0.087	0.074	0.063	0.050
0.12	0.093	0.086	0.076	0.050
0.20	0.106	0.100	0.097	0.050
0.25	0.117	0.112	0.111	0.050

gives the ratio of initial absolute roll displacement $\hat{\phi}$ to RMS roll σ_ϕ:

$$\frac{\hat{\phi}}{\sigma_\phi} = \sqrt{\frac{8\pi\xi_4 n_4}{1-\exp\left(-4\pi\xi_4 n_4\right)}} \tag{5.1}$$

where ξ_4 is the roll damping coefficient as a fraction of critical damping and n_4 is the number of roll cycles in the time series. For each time series provided by IMD with an initial roll displacement of at least 2 degrees and at least 2 roll cycles, the damping coefficient ξ_4 has been estimated by satisfying the above equation. Figure 5 shows the estimated roll damping coefficients as a function of roll amplitude. For the roll decay tests, the effective roll amplitude in Figure 5 is taken as $\sqrt{2}\sigma_\phi$. The estimated experimental damping values show a moderate amount of scatter, and tend to increase with roll amplitude due to increased viscous roll damping. Predicted roll damping values from SHIPMO7 are somewhat higher than the experimental results.

In the SHIPMO7 and PRECAL analyses for regular waves, the range of wave frequencies was 2 rad/s to 5 rad/s (model scale), similar to the range used for the hydroelastic model tests. However, for irregular wave computations, a wave frequency range of 1 rad/s to 9 rad/s was used to encompass the wave spectral energies.

For computations in irregular seas, attention must be given to the definition of the characteristic wave period. The IMD reports incorrectly use the term modal wave period T_0 (wave spectral energy density $S(T)$ is a maximum at period T_0) for what is actually the peak wave period T_p (wave spectral energy density $S(\omega)$ is a maximum at frequency $2\pi/T_p$). This report uses the correct term T_p instead of T_0. For the Bretschneider and JONSWAP spectra in SHIPMO7,

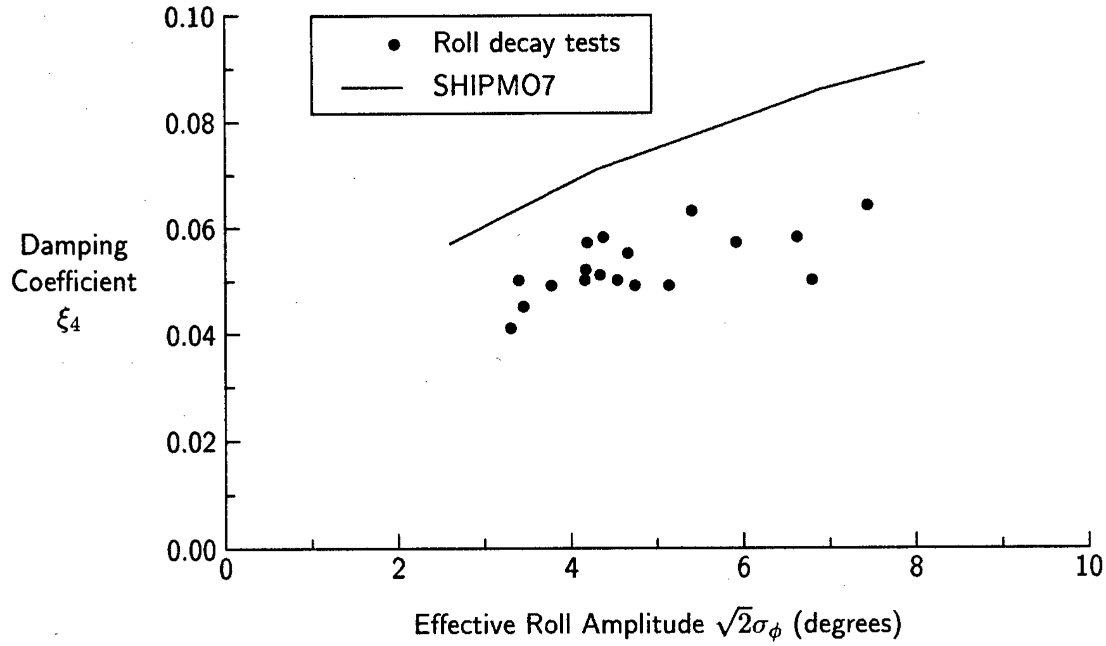

Figure 5: Roll Damping at Zero Ship Speed for Deep Departure Condition

the peak wave period is the characteristic period used as input. However, PRECAL requires the input wave period to be either an average period or a zero-crossing period T_z. The latter is chosen, and the conversion factor from T_p to T_z is 0.710 [21].

6 Description of IMD Experiments

The 1:20 scale hydroelastic model of the Canadian Patrol Frigate was designed and built by Fleet Technology Limited [6]. The final design was a six segment model with a continuous elastic backbone serving as the sole longitudinal support. Froude scaling was used, where lengths scale linearly and masses and forces are scaled by the cubic power of the linear scaling factor λ.

The model was built from fiberglass, with a backbone of carbon/epoxy composite. Self-propulsion was achieved by two small motors each powering a propeller. Rudder control was provided by a third motor, which was controlled by a human operator via telemetry. Safety restraint wires at the bow and stern were present in case control of the model was lost.

The model was segmented at stations 2.5, 5 (forward quarter point), 7.5, 10 (midships), and 13.7 (by SHIPMO7 convention, station 0 is FP and 20 is AP). The last segment was significantly larger than the others to accommodate the propulsion equipment. Strain gauges were attached to the backbone at each of the segment joints to measure the loads acting on the ship. An inertial reference system was fitted at the model center of gravity to allow measurement of the global motions of the ship.

Head seas (180 degrees) trials were performed in the Clearwater Towing Tank and oblique seas (135, 150 and 165 degrees) cases were performed in the Offshore Engineering Basin. Regular wave test cases were conducted for both deep departure and operational light conditions, but only the deep departure condition was considered for irregular waves. Data were collected at four different ship speeds, ranging from 4.1 to 17.0 knots (full-scale values). A full summary of regular wave test cases is presented in Table 4 and irregular wave cases are shown in Table 5. All irregular wave cases in Table 5 were run using a Bretschneider spectrum. For a heading of 180 degrees and ship speed of 8.2 knots, the tests were repeated with a JONSWAP spectrum.

For regular waves, data from the IMD tests are reported as non-dimensionalized response amplitude operators (RAOs). Dimensional values for the full-scale CPF are used for irregular wave responses.

Table 4: Regular Wave Test Cases

Weight Condition	Heading (degrees)	Froude number	U (knots) (full-scale)	Wave Steepnesses
Deep Departure	180	0.06	4.1	1/30, 1/20, 1/15
		0.12	8.2	1/30, 1/20, 1/15
		0.20	13.6	1/30, 1/20
		0.25	17.0	1/30, 1/20
	165	0.06	4.1	1/30, 1/20
		0.12	8.2	1/30, 1/20
		0.20	13.6	1/30, 1/20
		0.25	17.0	1/30
	135	0.12	8.2	1/30, 1/20
		0.20	13.6	1/30, 1/20
		0.25	17.0	1/30
Operational Light	180	0.06	4.1	1/20
		0.12	8.2	1/30, 1/20, 1/15
		0.20	13.6	1/20

Table 5: Irregular Wave Test Cases

Heading (degrees)	Froude number	U (knots) (full-scale)	H_s/T_p Pairs
180	0.06	4.1	4 m/9 s, 5 m/11 s, 6 m/13 s
	0.12	8.2	4 m/9 s, 5 m/11 s, 6 m/13 s
	0.20	13.6	4 m/9 s, 5 m/11 s, 6 m/13 s
	0.25	17.0	4 m/9 s, 5 m/11 s, 6 m/13 s
165	0.06	4.1	5 m/11 s
	0.12	8.2	5 m/11 s
	0.20	13.6	5 m/11 s
150	0.06	4.1	5 m/11 s
	0.12	8.2	5 m/11 s
	0.20	13.6	5 m/11 s
135	0.06	4.1	5 m/11 s
	0.12	8.2	5 m/11 s
	0.20	13.6	5 m/11 s

7 Presentation of Experimental and Numerical Results

This section gives some representative plots of comparisons between experimental data and predictions from SHIPMO7, PRECAL, and MOSOLV.

7.1 Regular Waves

For regular waves, the numerical predictions are for a wave steepness H/λ of 1/30 for both the deep departure condition and the operational light condition, which was tested only in head seas. For SHIPMO7 and PRECAL, vertical plane predictions are strictly linear while lateral plane predictions include nonlinearities from roll damping. MOSOLV predictions are included for a limited number of cases to demonstrate the deficiencies of the code. Motion and load amplitudes are presented as non-dimensional values. Non-dimensional bending moments are multiplied by a factor of 1000 and shear forces by 100.

Although IMD performed some head seas verification trials in the Offshore Engineering Basin, experimental results for all head seas cases in this study were obtained from Towing Tank test data. Head seas comparisons were done for deep departure and operational light loading conditions. For head seas, only vertical plane motions and sea loads were considered. All sea loads (moments, shears, and torsions) were analyzed at five locations: stations 2.5, 5.0, 7.5, 10.0 and 13.7 (by SHIPMO7 convention). Figures 6 to 11 give representative regular head seas results for the deep departure condition. Figures 12 to 16 give representative regular oblique seas results for the deep departure condition with a heading of 135 degrees and a Froude number of 0.12.

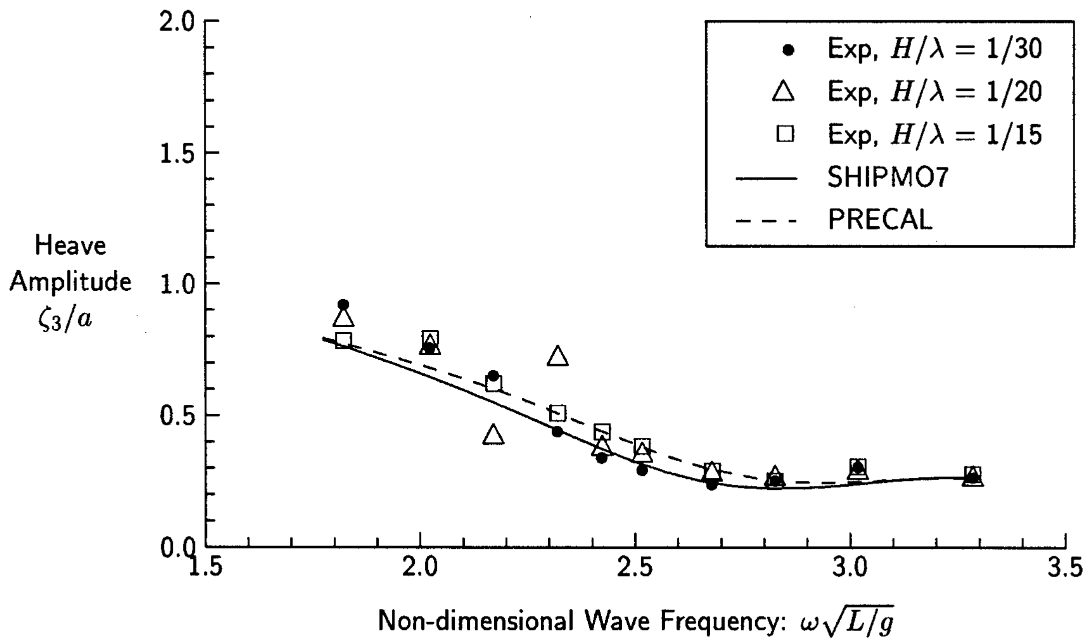

Figure 6: Heave Motion, Heading = 180 degrees, Deep Departure, Fn = 0.12

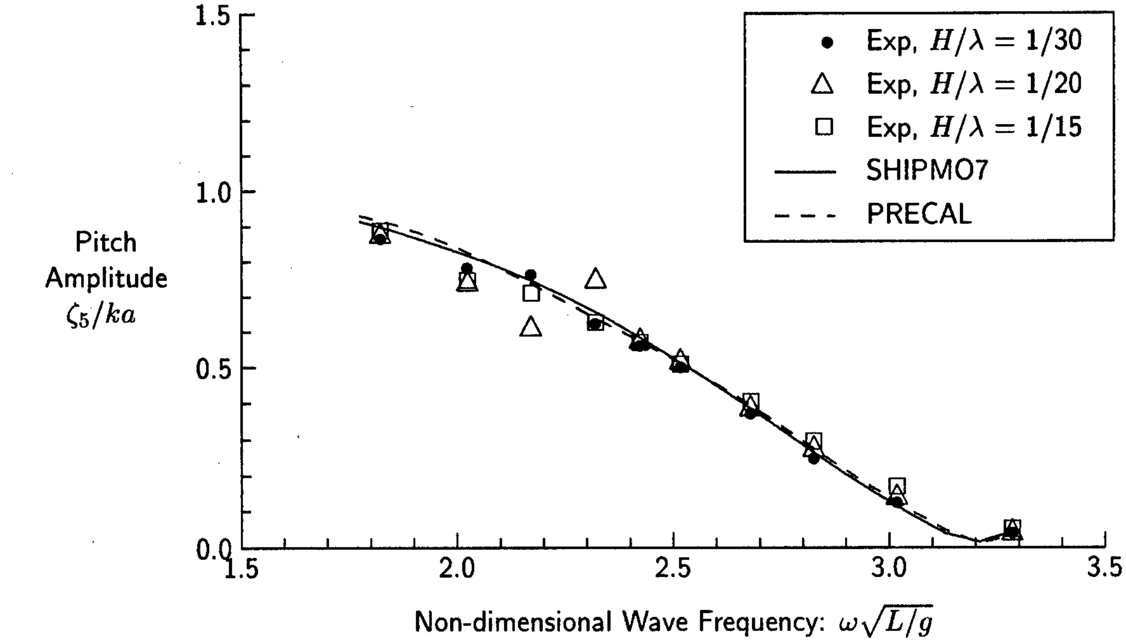

Figure 7: Pitch Motion, Heading = 180 degrees, Deep Departure, $Fn = 0.12$

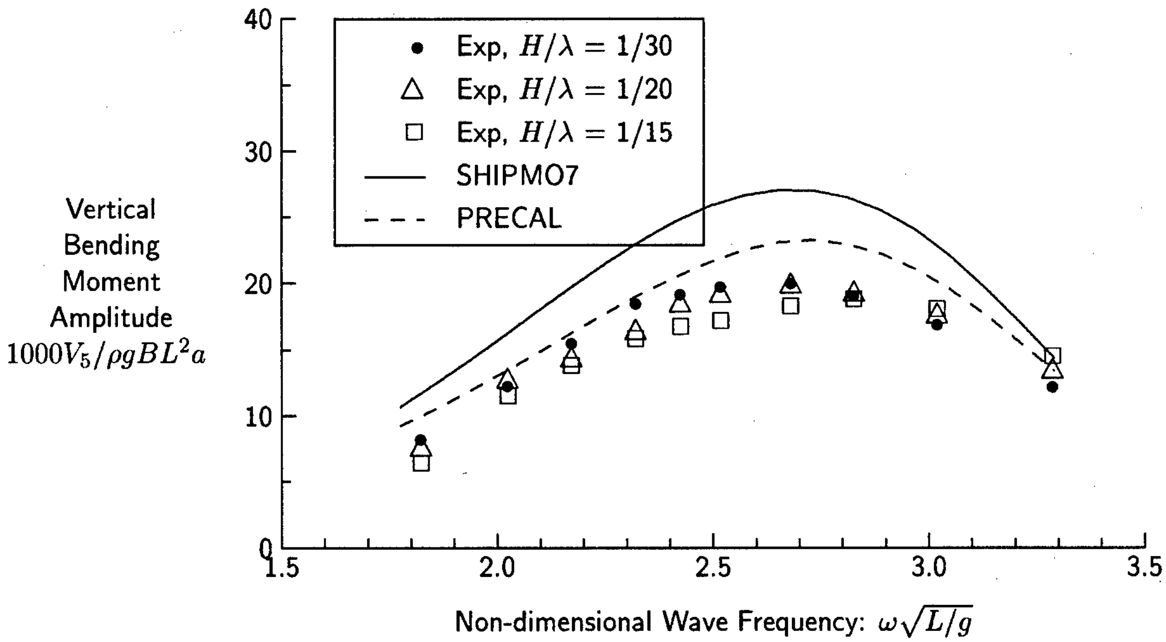

Figure 8: Vertical Bending Moment at Station 10.0, Heading = 180 degrees, Deep Departure, $Fn = 0.12$

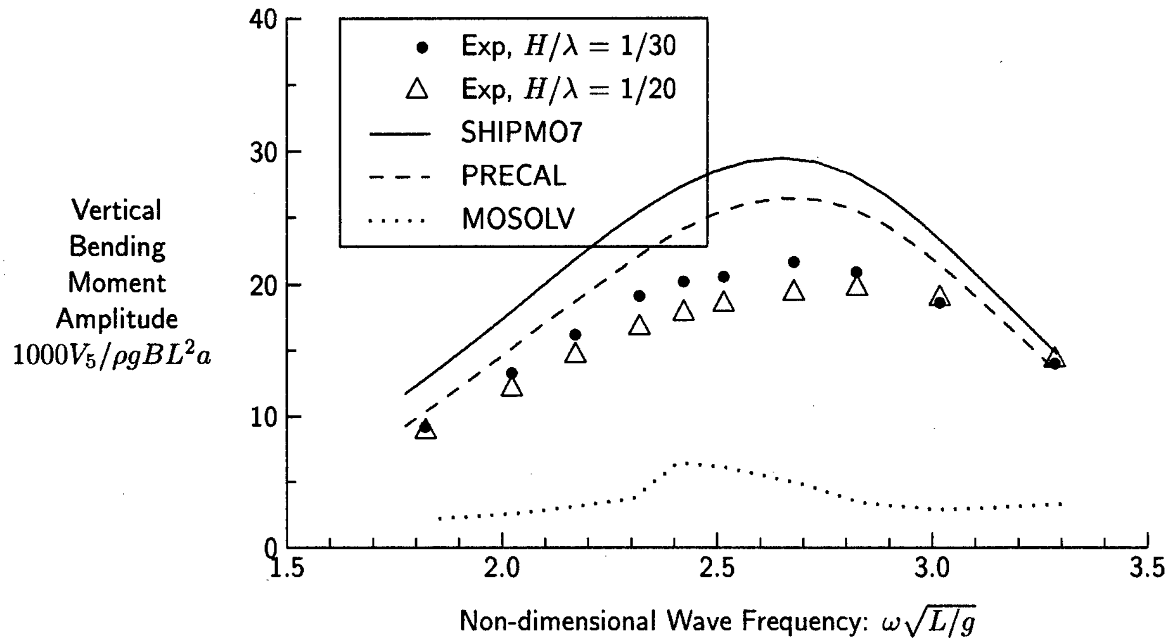

Figure 9: Vertical Bending Moment at Station 10.0, Heading = 180 degrees, Deep Departure, $Fn = 0.20$

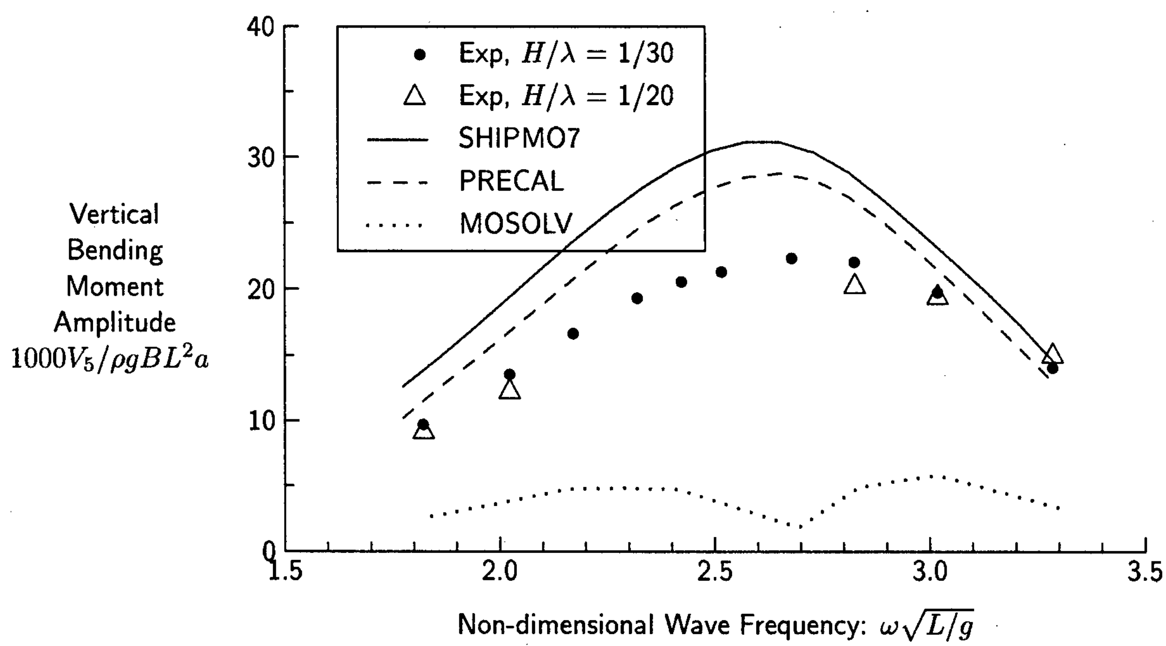

Figure 10: Vertical Bending Moment at Station 10.0, Heading = 180 degrees, Deep Departure, $Fn = 0.25$

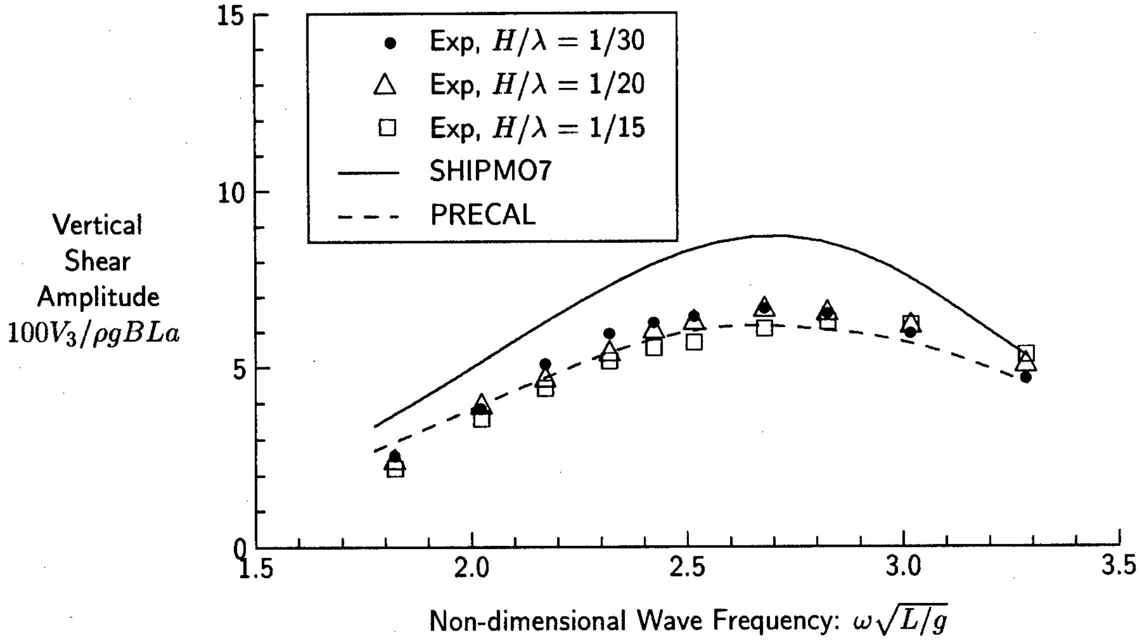

Figure 11: Vertical Shear Force at Station 5.0, Heading = 180 degrees, Deep Departure, Fn = 0.12

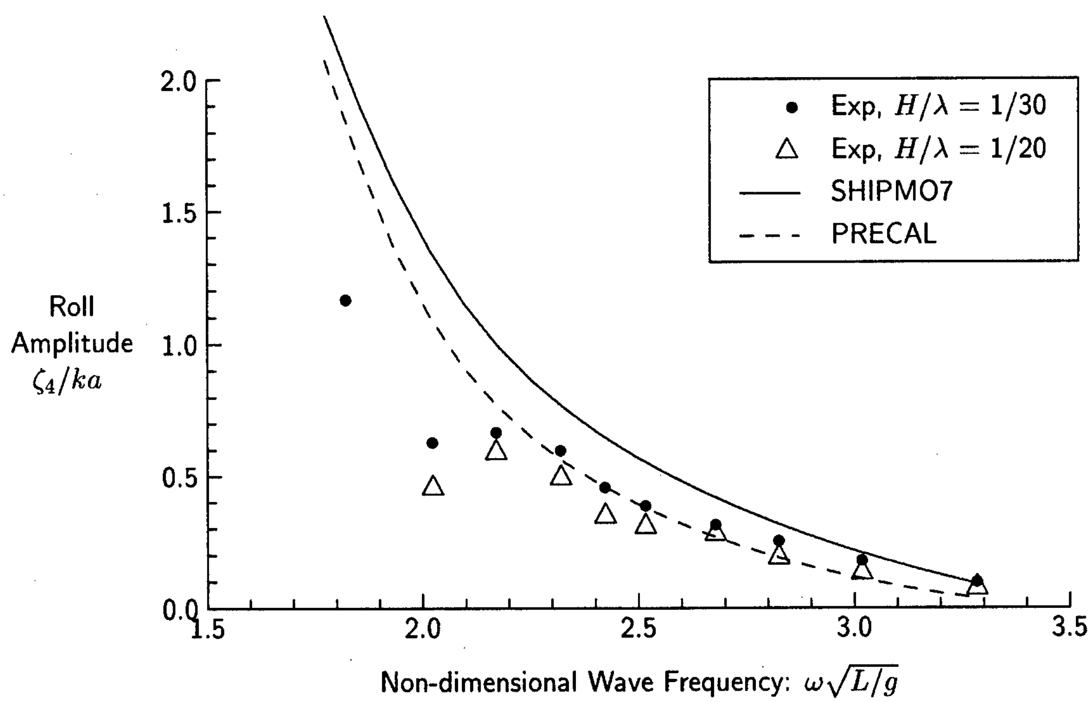

Figure 12: Roll Motion, Heading = 135 degrees, Deep Departure, $Fn = 0.12$

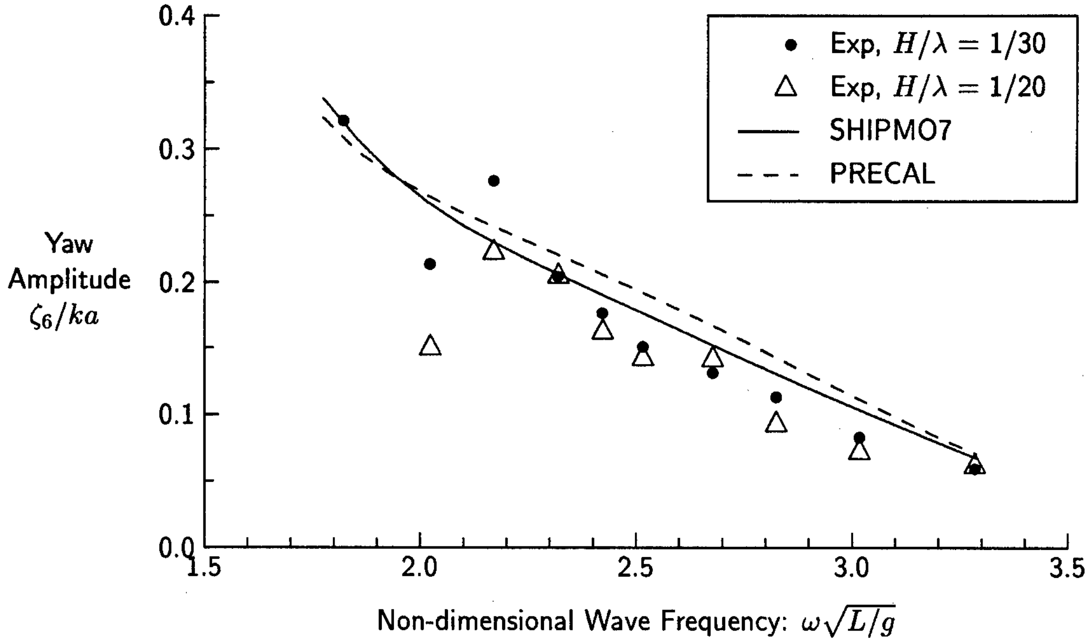

Figure 13: Yaw Motion, Heading = 135 degrees, Deep Departure, $Fn = 0.12$

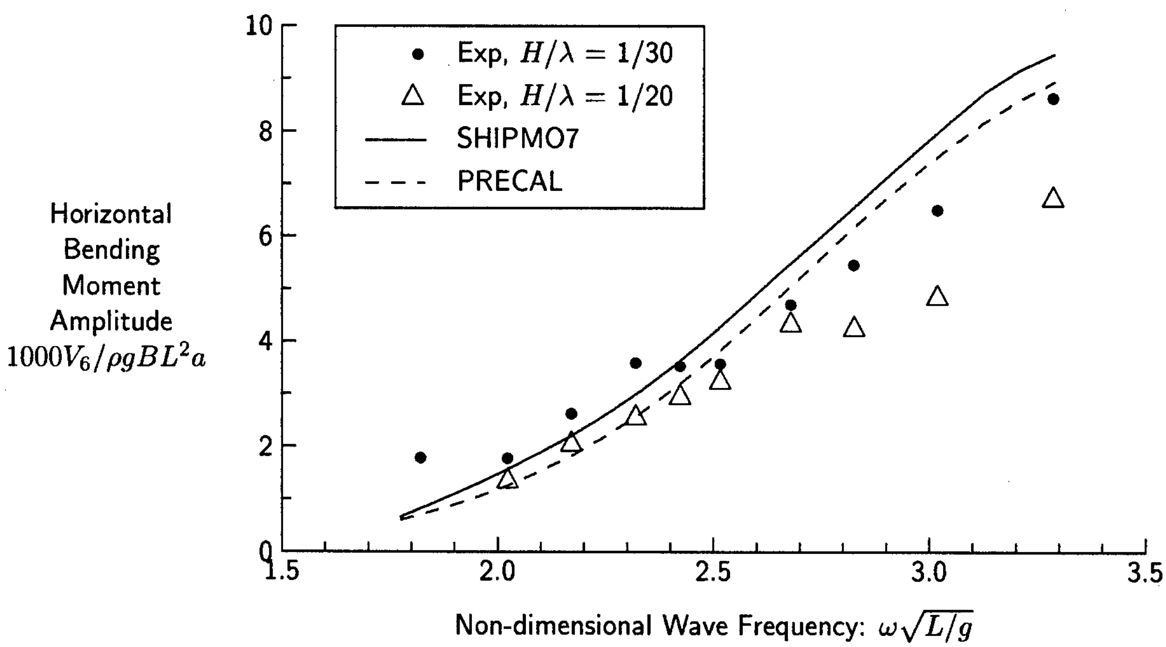

Figure 14: Horizontal Bending Moment at Station 10.0, Heading = 135 degrees, Deep Departure, $Fn = 0.12$

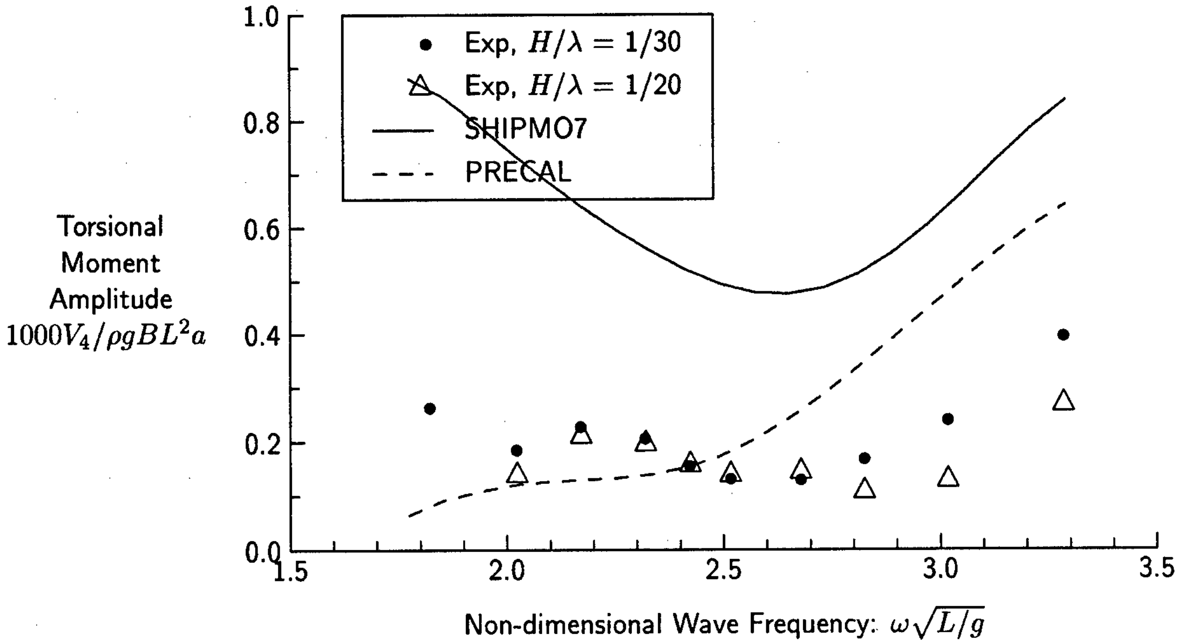

Figure 15: Torsional Moment at Station 10, Heading = 135 degrees, Deep Departure, $Fn = 0.12$

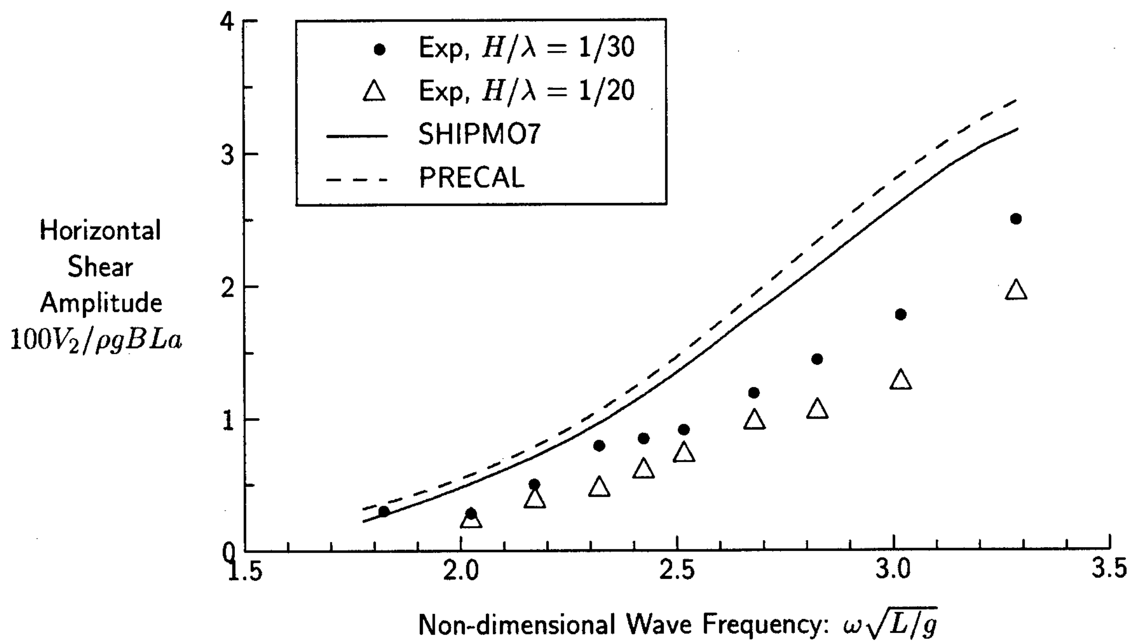

Figure 16: Horizontal Shear Force at Station 5.0, Heading = 135 degrees, Deep Departure, $Fn = 0.12$

7.2 Irregular Waves

Only the deep departure load condition was tested in irregular waves. Motions for head seas cases are presented as a function of significant wave height and as a function of ship speed for oblique cases. All sea loads are presented as a function of station number. Ship speeds and station locations used for irregular waves are identical to those used for regular waves. Bretschneider spectra were used for both head and oblique seas. Additional head seas tests were performed using JONSWAP spectra. Full-scale dimensional RMS values are used for all irregular wave cases. For sea loads, the PRECAL RMS values were obtained after correcting a bug in the code RESCAL. Figures 17 to 25 give selected irregular seas results for the deep departure condition with Bretschneider spectra.

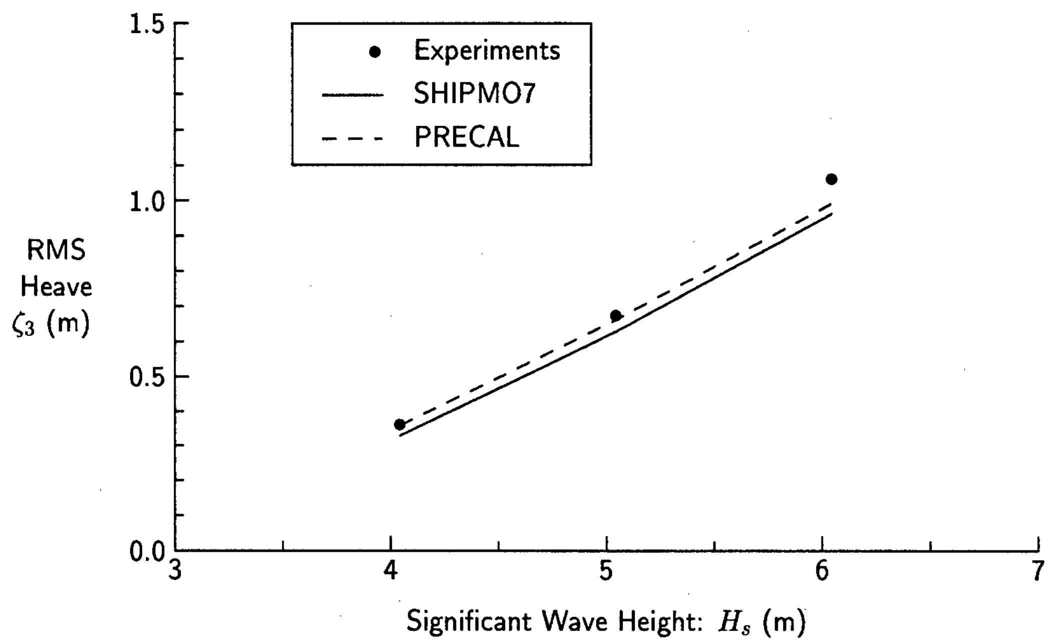

Figure 17: Heave Motion, Heading = 180 degrees, $F_n = 0.12$, Bretschneider Spectrum

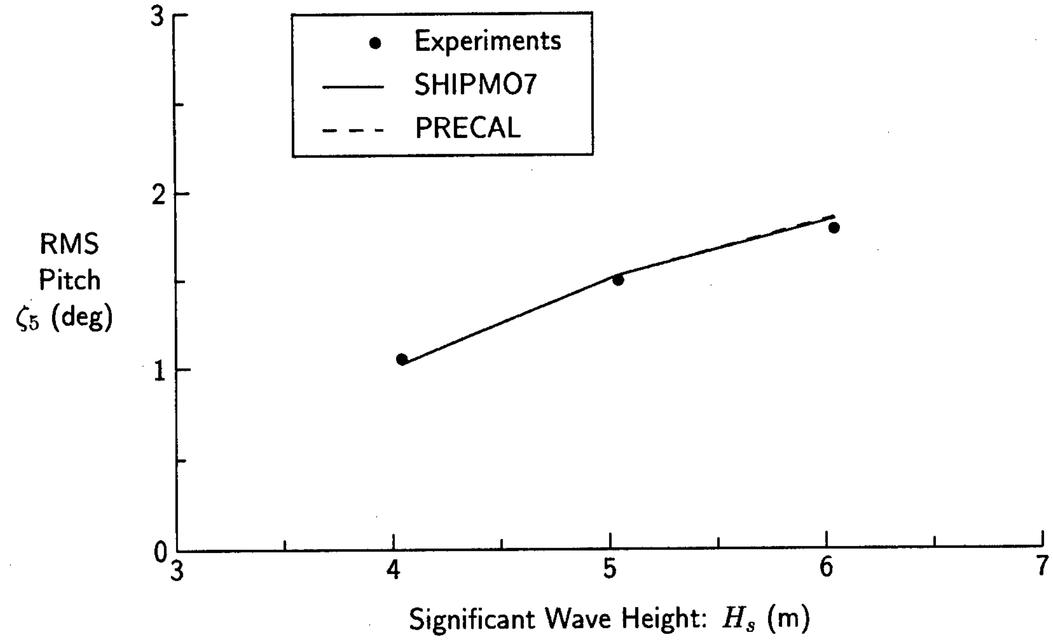

Figure 18: Pitch Motion, Heading = 180 degrees, F_n = 0.12, Bretschneider Spectrum

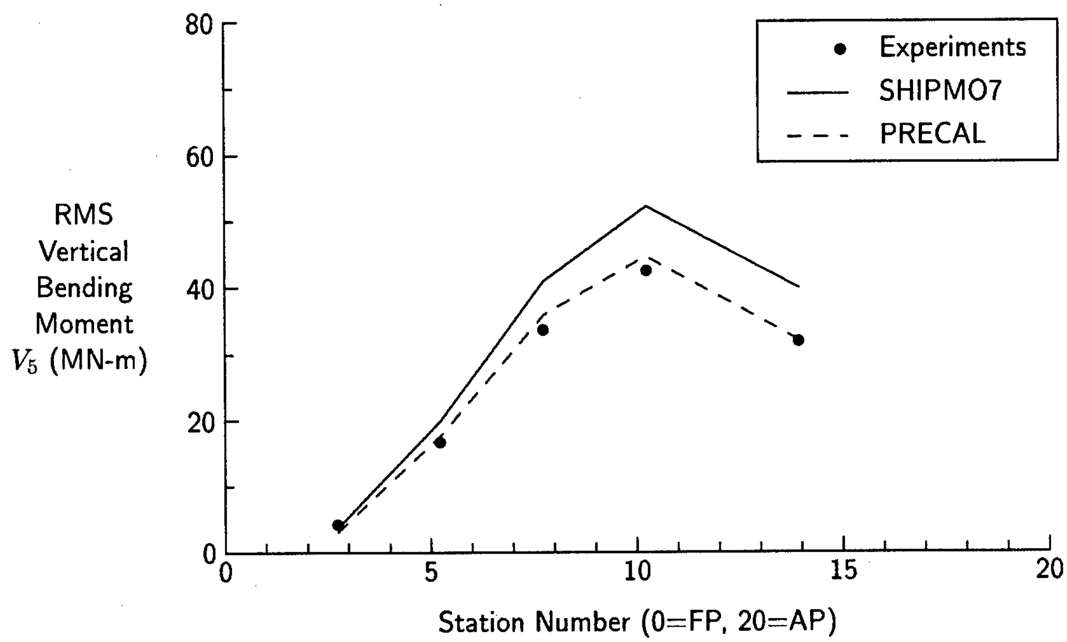

Figure 19: Vertical Bending Moment, Heading = 180 degrees, F_n = 0.12, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

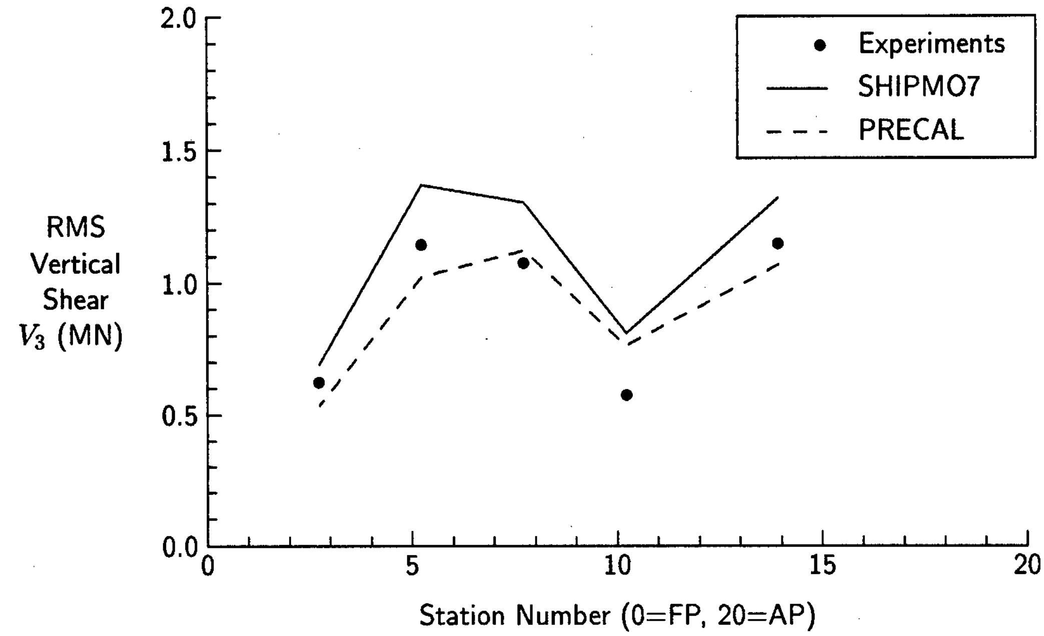

Figure 20: Vertical Shear Force, Heading = 180 degrees, F_n = 0.12, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

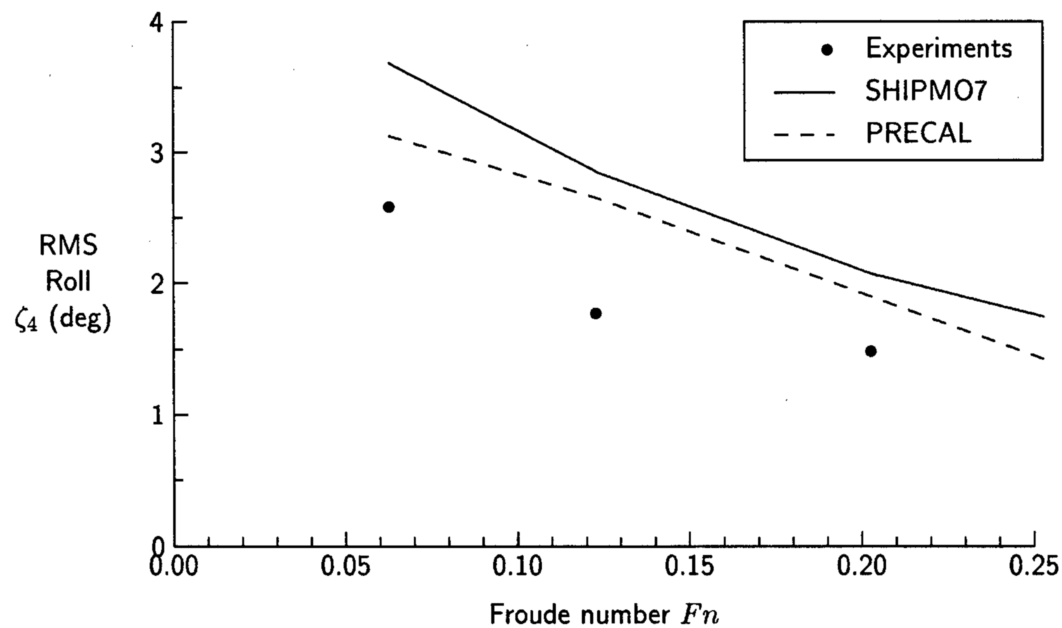

Figure 21: Roll Motion, Heading = 135 degrees, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

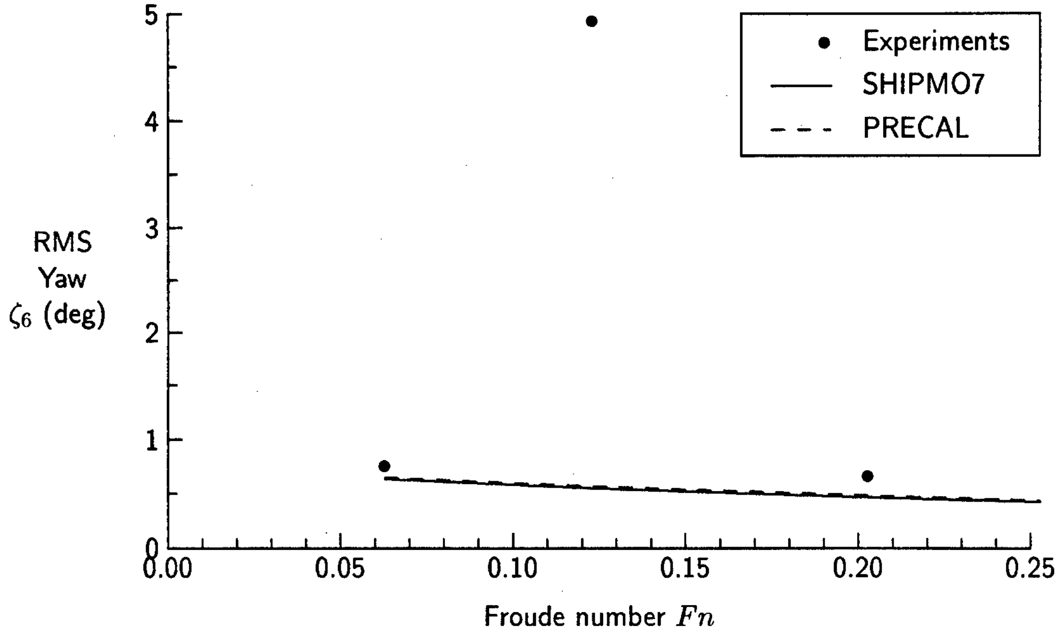

Figure 22: Yaw Motion, Heading = 135 degrees, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

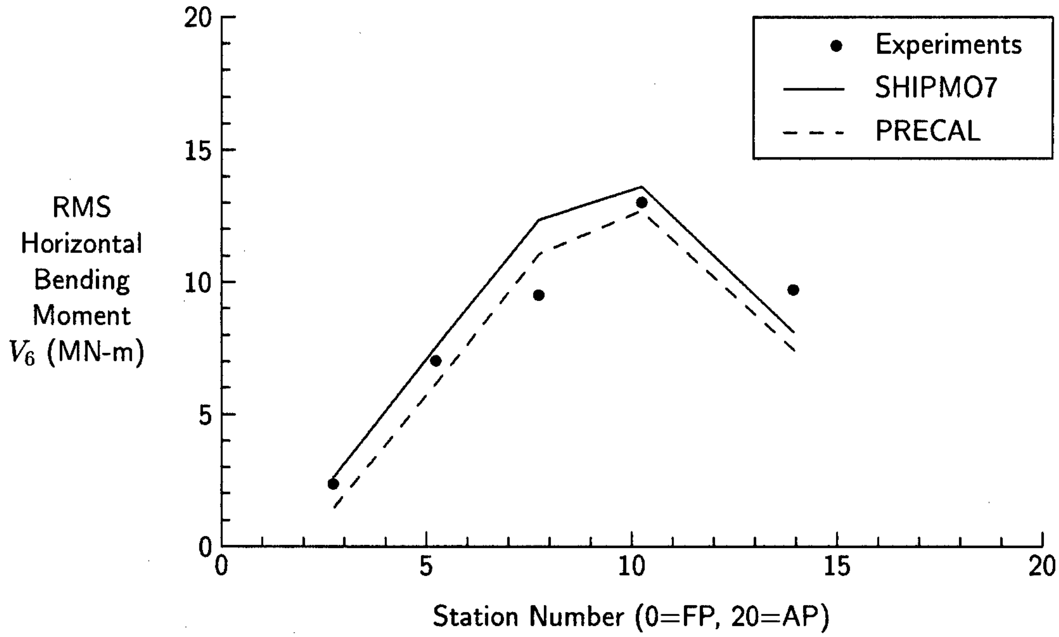

Figure 23: Horizontal Bending Moment, Heading = 135 degrees, Fn = 0.20, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

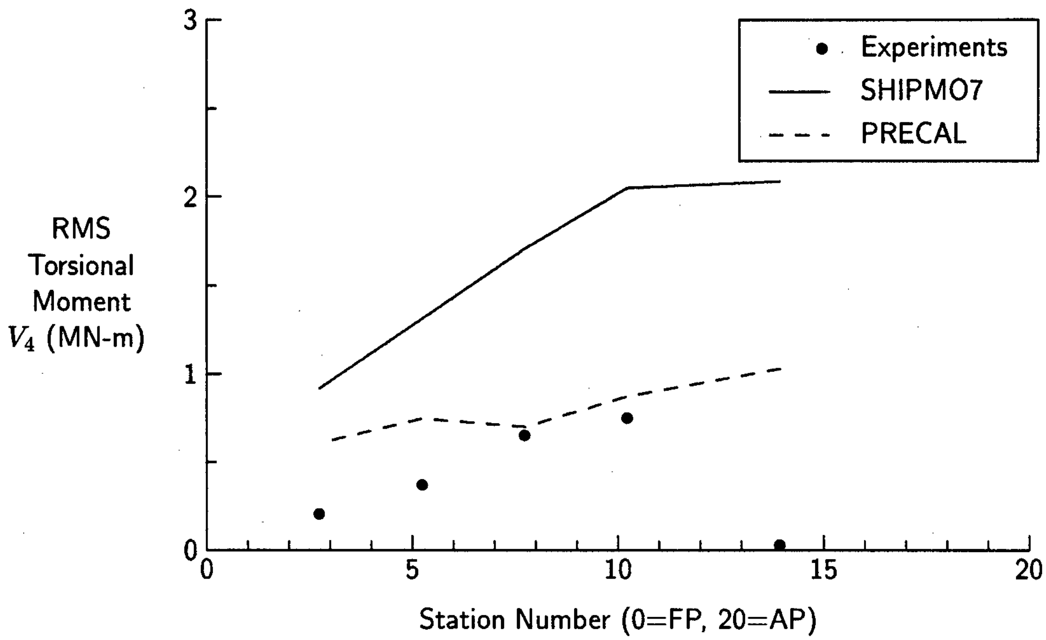

Figure 24: Torsional Moment, Heading = 135 degrees, Fn = 0.12, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

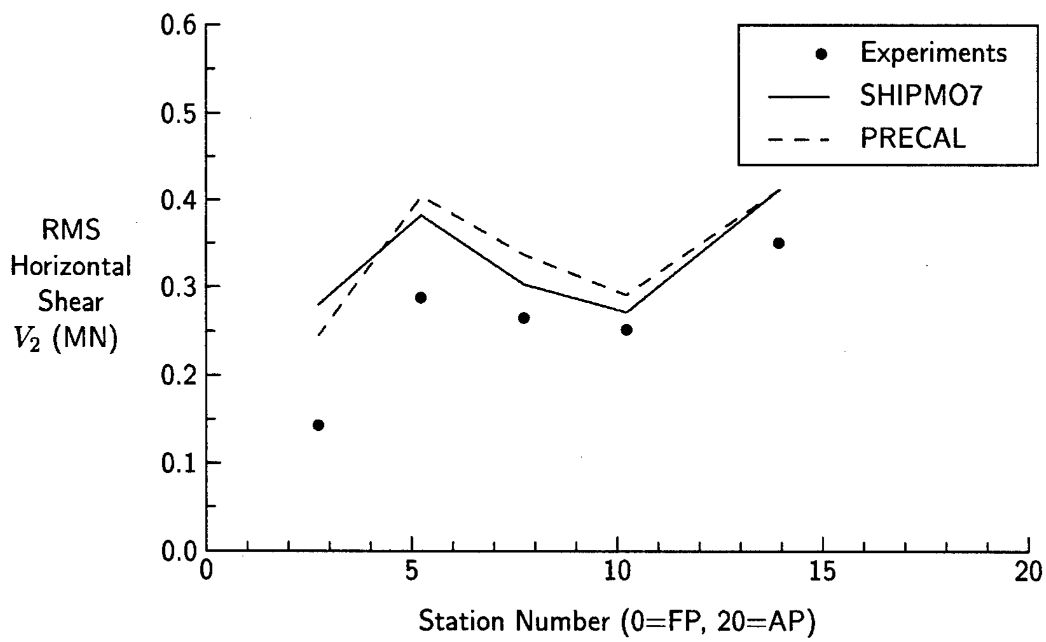

Figure 25: Horizontal Shear Force, Heading = 135 degrees, Fn = 0.12, H_s = 5 m, T_p = 11 s, Bretschneider Spectrum

8 Discussion of Results

In general, SHIPMO7 and PRECAL consistently demonstrate good agreement with each other and with the experimental data. In particular, comparisons for ship motions are good for most test conditions. For sea load predictions, both codes typically overpredict the vertical bending moments and shear forces. PRECAL demonstrates somewhat better accuracy in predicting sea loads than SHIPMO7.

MOSOLV predictions are generally poor, particularly for sea loads (e.g. Figures 9 and 10). Due to the poor quality of MOSOLV predictions, further discussion will be limited to SHIPMO7 and PRECAL.

8.1 Heave

As expected, both SHIPMO7 and PRECAL give excellent predictions of heave motions. In regular head seas, the experimental results appear to be consistent and show limited variation with wave steepness. There is a surprising amount of scatter for the regular seas experimental data at a heading of 135 degrees, with SHIPMO7 and PRECAL following the experimental trends. At a heading of 165 degrees in regular seas, there is less experimental scatter than at 135 degrees and the numerical predictions are very good. There is a general trend of less experimental scatter and improved predictions at higher wave frequencies.

In irregular seas, SHIPMO7 and PRECAL give excellent agreement with the experimental data for all cases except a heading of 135 degrees at a Froude number of 0.12. The discrepancy at this heading is consistent with the regular seas results.

8.2 Roll

In regular seas, the experimental roll data are very consistent and show little variation with wave steepness for both headings (135 and 165 degrees). SHIPMO7 shows overprediction at 135 degrees while PRECAL gives better agreement. As mentioned previously, the SHIPMO7 input $\overline{KG}$ values for the ship and all sections were increased by 0.24 m full scale so that the computed metacentric height would coincide with the measured metacentric height. When the original $\overline{KG}$ value of 6.26 m full scale was used, the SHIPMO7 roll excitation forces were significantly larger, causing greater overprediction of roll motions. At a heading of 165 degrees in regular seas, SHIPMO7 gives very good agreement with the experimental values while PRECAL tends to underpredict.

In irregular seas, SHIPMO7 and PRECAL give similar results, with some overprediction at a heading of 135 degrees but better agreement with experiments at headings of 150 and 165 degrees.

8.3 Pitch

In regular seas, the experimental pitch motions are very consistent and show little variation with wave steepness for all headings. Both SHIPMO7 and PRECAL give excellent agreement with experimental data for both regular and irregular seas.

8.4 Yaw

In regular seas, the experimental yaw data are consistent and exhibit little variation with wave steepness. SHIPMO7 and PRECAL predictions are very good, with the exception of underprediction at lower frequencies at a heading of 165 degrees for Froude numbers of 0.06 and 0.25.

In irregular seas, the agreement between experimental data and numerical predictions is much worse than for regular seas. The very high experimental value at a heading of 135 degrees and Froude number of 0.12 is likely incorrect. The numerical codes also significantly underpredict the experimental results at headings of 150 and 165 degrees.

8.5 Vertical Bending Moment

In regular waves, the experimental vertical bending moment data appear to be consistent. Vertical bending moments exhibit significant dependence on wave steepness, with nondimensional bending moment usually decreasing with increasing wave steepness. Both SHIPMO7 and PRECAL overpredict vertical bending moment at midships, with PRECAL giving better results than SHIPMO7. The degree of overprediction for both codes increases as Froude number increases. The poorest agreement between experiments and predictions occurs for the operational light condition at station 2.5. This poor agreement is likely due to an incorrect weight distribution for the foremost model segment, as discussed in Section 5.

In irregular seas, SHIPMO7 and PRECAL give good predictions of bending moment at all stations. At low Froude numbers, PRECAL is very accurate while SHIPMO7 is somewhat less accurate. At high Froude numbers, PRECAL predictions deteriorate somewhat but are still more accurate than SHIPMO7.

8.6 Horizontal Bending Moment

In regular waves, the horizontal bending moment experimental data show quite good consistency, with moderate dependence on wave steepness. SHIPMO7 and PRECAL give good agreement with experiments. As expected, this agreement tends to deteriorate as Froude number increases.

In irregular seas, both SHIPMO7 and PRECAL give very good agreement for the horizontal bending moment distribution.

8.7 Torsion

The torsion data indicate that the measurements were not working at station 13.7 for some of the tests. In regular waves, SHIPMO7 torsion predictions are typically much greater than experimental results, while PRECAL predictions appear to be better.

In irregular seas, PRECAL gives reasonable agreement while SHIPMO7 predictions are approximately twice as large as experimental values.

8.8 Vertical Shear

In regular waves, the vertical shear predictions appear to be consistent, with a moderate dependence on wave steepness. Agreement between predictions and experiments exhibits trends

similar to those for vertical bending moment. Both SHIPMO7 and PRECAL tend to overpredict vertical shear, with PRECAL giving better results than SHIPMO7. Results are somewhat better at lower Froude numbers.

In irregular waves, SHIPMO7 and PRECAL give good agreement with the experimental vertical shear distribution, with SHIPMO7 consistently overpredicting shear force.

8.9 Horizontal Shear

In regular waves, the horizontal shear predictions appear to be consistent, with moderate dependence on wave steepness. Both SHIPMO7 and PRECAL tend to overpredict horizontal shear.

In irregular waves, SHIPMO7 and PRECAL give good agreement with the experimental values at all stations except for Station 2.5, where there is significant overprediction.

9 Sources of Discrepancies between Predictions and Experiments

Discrepancies between the code predictions and experimental results could be due to general deficiencies of the codes or could be specific to the CPF experiments. Consideration of the current results and Reference 1 for a warship model can help to isolate possible sources of inaccuracy.

In general, comparison results for the CPF are inferior to those for the warship model. Possible sources of discrepancies for the CPF include the following:

- the hull geometry violates slenderness assumptions in numerical predictions,
- the experimental motions and loads have errors,
- the mass distribution for the CPF model is incorrect,
- PRECAL assumes that all sections have a transverse metacentric height equal to the ship metacentric height,
- SHIPMO7 roll damping predictions are incorrect,
- rudder motions, which are ignored by the numerical predictions, affect lateral plane motions and loads,
- nonlinear effects which are ignored by the numerical predictions.

Figure 26 shows the waterplanes for the CPF and warship models. The most important difference between the hull forms is that the CPF has a wide transom stern while the warship has a narrow stern. Considering the slenderness assumptions of strip theory, SHIPMO7 should be able to give very good results for the warship but less accurate results for the CPF. The three-dimensional code PRECAL should give better results than SHIPMO7 for a transom stern ship; however, PRECAL results will also deteriorate as transom width increases because of the assumption that the steady flow diffraction potential is negligible and because the PRECAL predictions use the zero-speed Green function. Figure 27 shows vertical bending moment at

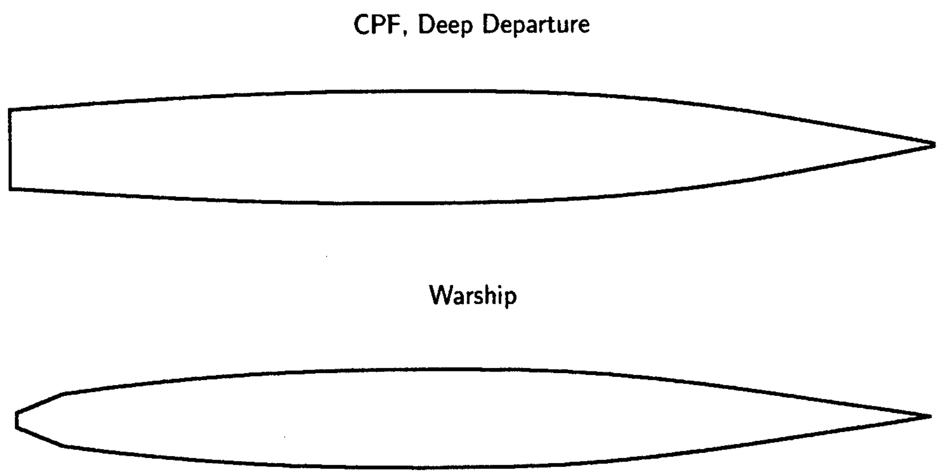

Figure 26: Waterplanes for CPF and Warship Model

midships in head seas for the warship at $Fn = 0.21$. PRECAL and SHIPMO7 give predictions that are close to the experimental results. In contrast, Figures 8 to 10 show SHIPMO7 consistently overpredicts vertical bending moment at midships in head seas for the CPF. For all four speeds considered in this study, PRECAL results are always better than SHIPMO, suggesting that three dimensional effects are important for the CPF. The accuracy of both SHIPMO7 and PRECAL predictions decrease as ship speed increases; thus, the dynamic waterline and steady diffraction potential, which are ignored by both codes, are likely significant for the CPF. In contrast, predictions of vertical bending moment at midships for the narrow stern warship model are excellent at Froude numbers of 0.21 and 0.29. In summary, the non-slender CPF stern likely causes significant prediction errors for both SHIPMO7 and PRECAL.

The accuracy of experimental motions and sea loads can be partially assessed by examining the consistency of the experimental data. With the exception of torsion at Station 13.7 for some tests, the experimental data given in the appendices have consistent trends, suggesting that they are correct.

Most aspects of the input mass properties for the CPF model are likely correct; however, some significant errors appear to exist. As discussed in Section 5, the sectional mass distribution for the operational light condition was inconsistent with the inertial properties of the foremost model segment. The sea loads comparisons for the operational light condition suggest that the total mass of the foremost segment was likely correct but an incorrect longitudinal centre of gravity likely introduced significant errors to predicted vertical bending moments.

As mentioned previously, there were no measurements of segment roll gyradii; thus, the sectional distribution of roll gyradii had to be estimated. Inaccuracies of estimated sectional roll gyradii likely introduced significant errors to predicted torsion values. Possible errors in sectional $\overline{KG}$ values may have also introduced errors in torsion predictions. As discussed earlier, the measured $\overline{GM}$ value for the ship suggested a possible error of 3 percent in the reported ship $\overline{KG}$ value.

For torsion calculations, the assumption by PRECAL that all sections have the same metacentric height introduces major errors for the CPF model, which has a low metacentric height

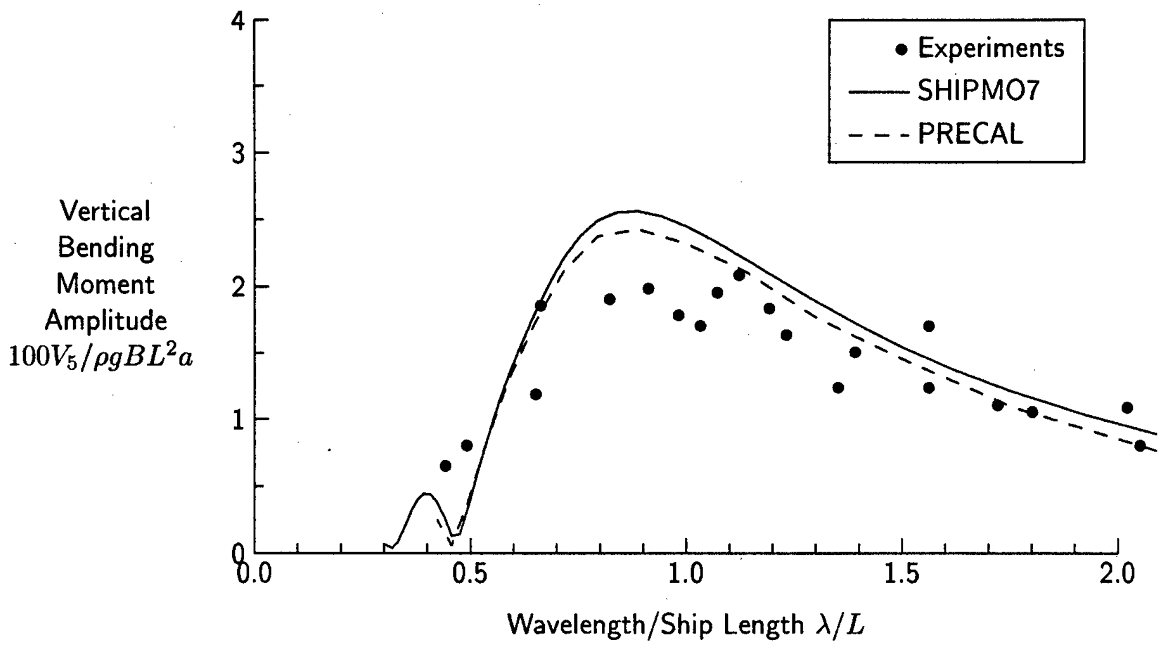

Figure 27: Vertical Bending Moment at Midships in Regular Head Seas for Warship at $Fn = 0.21$

forward of midships and a high metacentric height aft of midships. In contrast, SHIPMO7 correctly considers the variation of sectional metacentric height. The better agreement with experiments by PRECAL is more likely due to chance than to superior prediction of relevant force components. The distribution of sectional metacentric height for the CPF model causes torsion at midships to be very sensitive to roll displacement. Consequently, differences between experimental and predicted roll motions can cause large differences for torsion.

For regular waves at a heading of 135 degrees, the numerical roll predictions are significantly greater than experimental results at low wave frequencies, at which the wave encounter frequency approaches the ship roll natural frequency. A possible explanation for the roll overprediction is that SHIPMO7 underestimates roll damping, which greatly influences roll amplitude in the vicinity of roll resonance; however, the roll decay test results of Figure 5 indicate that SHIPMO7 is more likely to overpredict rather than underpredict roll damping for the CPF model. The roll overpredictions at low wave frequencies for a heading of 135 degrees are more likely due to inaccuracies of other hydrodynamic force terms. Examination of hydrodynamic force components indicated that roll-sway and roll-yaw coupling terms are relatively large; thus, a number of hydrodynamic terms could cause the roll overprediction.

The neglect of rudder motions by the numerical codes can cause errors in predicted ship motions and loads in the lateral plane. For the regular wave experiments, the good agreement between measured and predicted yaw motions suggests that the rudder motions had a relatively small effect on ship motions in the lateral plane. Rudder motions were likely greater for the irregular wave tests, causing more erratic experimental results and poorer agreement by the numerical codes. Horizontal shear and bending moment predictions give good agreement with experiments, suggesting that these sea loads were not significantly affected by rudder motions.

Regular wave tests conducted at various wave steepnesses provide insight regarding the importance of nonlinear effects. The experimental results suggest that nonlinear effects do not have a major influence on ship motions, with the possible exception of heave at a heading of 135 degrees. As expected, sea loads are more sensitive than ship motions to nonlinear effects. Nonlinear effects have the greatest influence on loads at Station 2.5, which is expected because the foremost portion of the ship has the greatest flare, thus violating the vertical wall assumption of linear theory.

10 Further Examination of SHIPMO7 Torsion Predictions

The relatively poor agreement between SHIPMO7 and experimental torsion values warrants further examination. Of major consideration is whether torsion predictions are correctly implemented in SHIPMO7.

The good agreement between SHIPMO7 torsion predictions and experimental data for the warship of Lloyd, Brown, and Anslow [2, 3] suggests that SHIPMO7 has a correct implementation of strip theory. The warship model has a narrow transom and nearly vertical sides in the vicinity of the waterline, making it well suited to strip theory modelling. Furthermore, the warship model tests were conducted in waves of low steepness, minimizing the influence of nonlinear effects. In contrast, the wide transom of the CPF violates slenderness assumptions of strip theory. The CPF transom also has a shallow draft, which will lead to significant nonlinearities. Based on the results for the warship and the CPF, it is suggested that the SHIPMO7 torsion predictions are correctly implemented and that poor results are due primarily to limitations of strip theory.

Given the good torsion results for the warship and the poor results for the CPF, it is worthwhile to examine SHIPMO7 torsion predictions for a third ship. Figures 28 to 36 show experimental data and SHIPMO7 predictions of torsion at midships for a Series 60 model with a block coefficient of 0.80 tested by Wahab [22]. A slight modification was made to program SHIPMO7 to compute the lateral responses for a constant wave height of $0.02L$ for all wave frequencies. Agreement between SHIPMO7 and experimental values is generally better than for the CPF but worse than for the warship. A possible source of error for the torsion predictions is that Wahab does not give the heights of the vertical centres of gravity for the two model segments; thus, it was assumed that the two segments have the same height for the centre of gravity, which is based on the reported metacentric height. Another likely cause of discrepancies between experimental and prediction values is that the hull form is quite full and violates slenderness assumptions of strip theory.

In general, it appears that the limitations of strip theory lead to marginal predictions of torsional loads. Another problem for torsion predictions is that roll inertial properties required for computations are often unavailable.

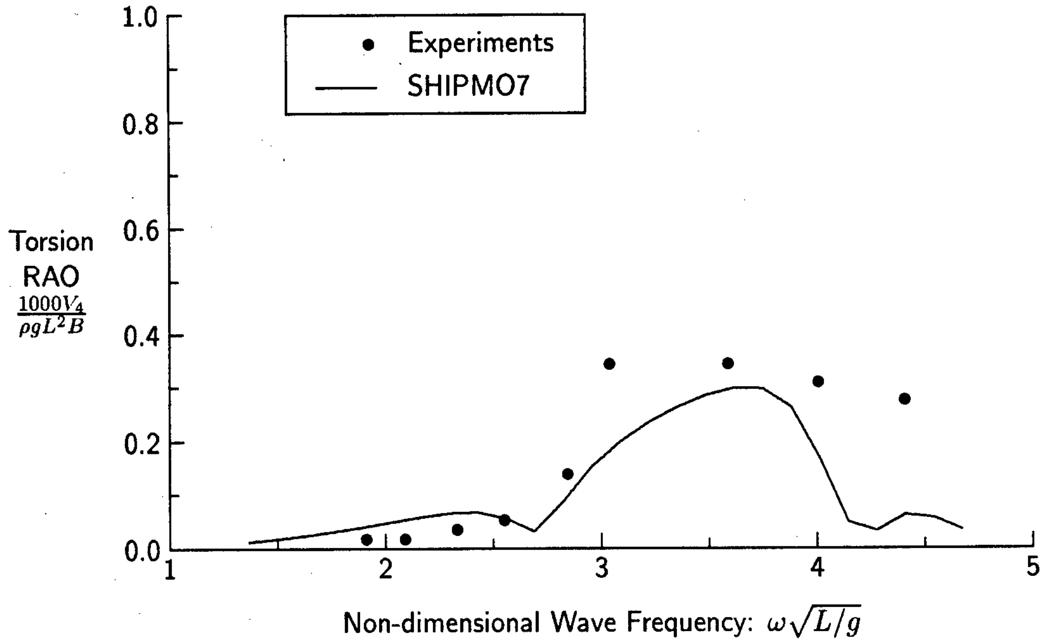

Figure 28: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 10 degrees

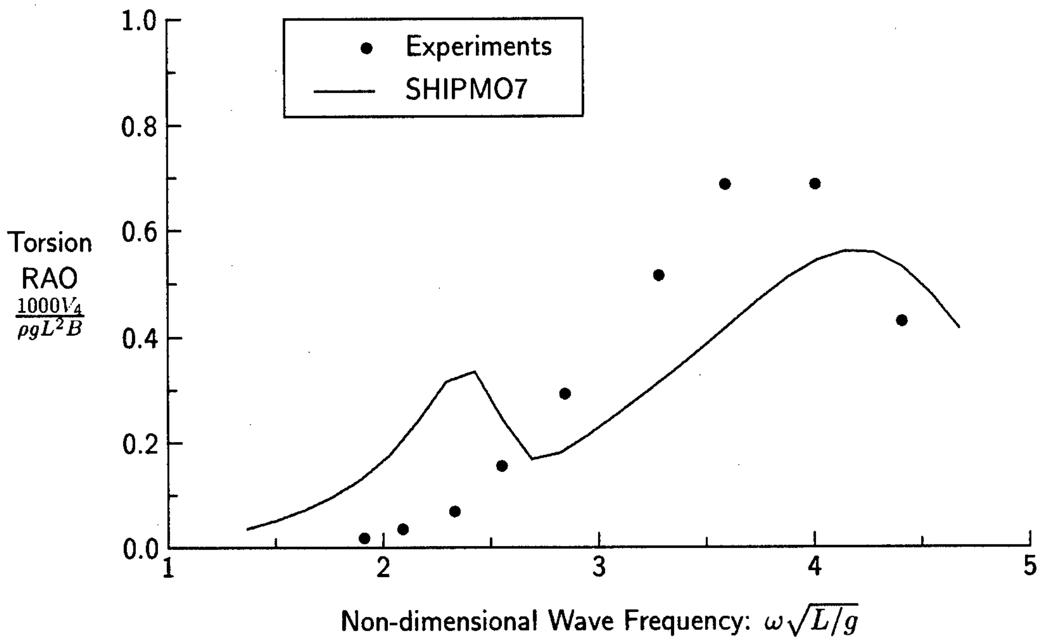

Figure 29: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 30 degrees

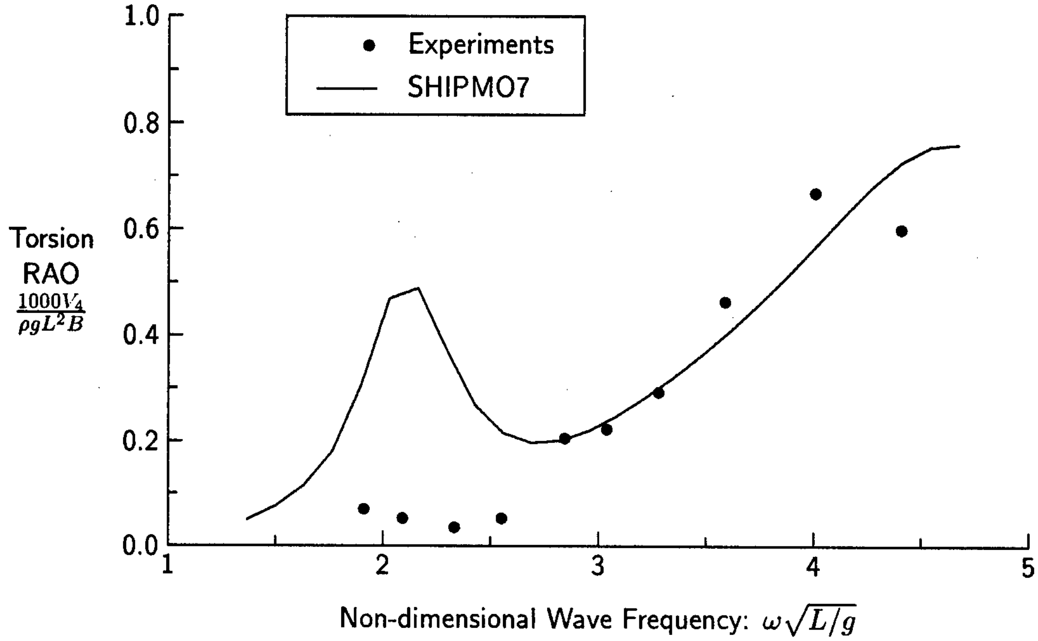

Figure 30: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 50 degrees

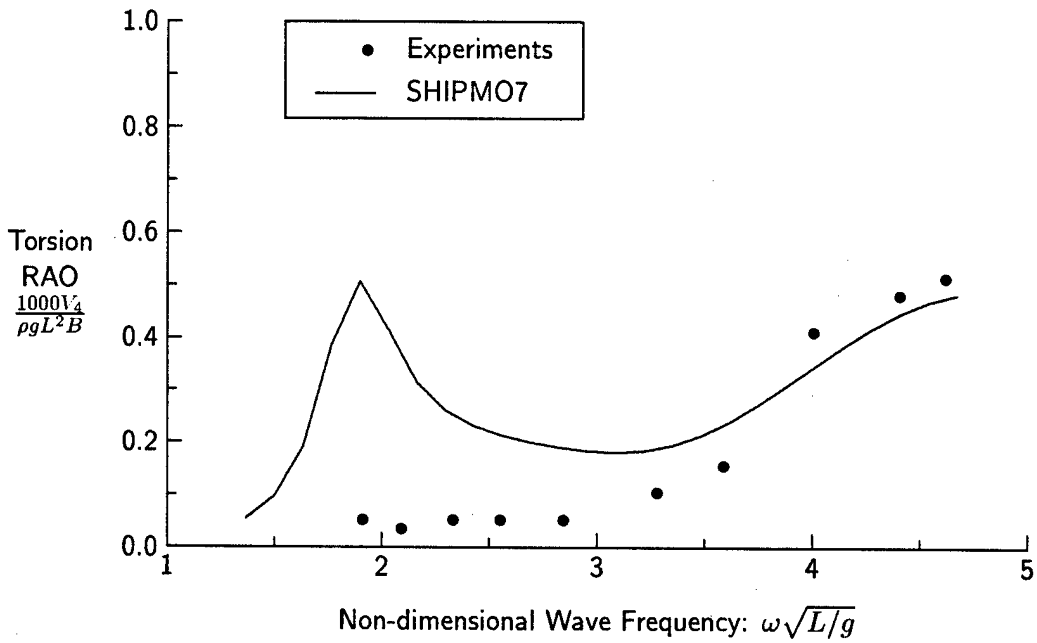

Figure 31: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 70 degrees

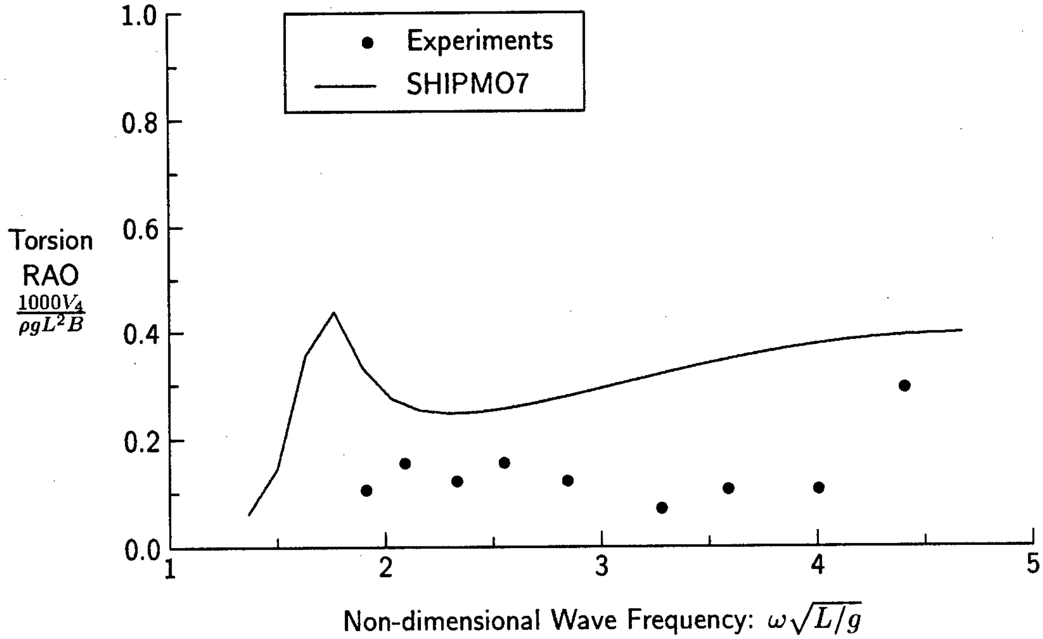

Figure 32: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 90 degrees

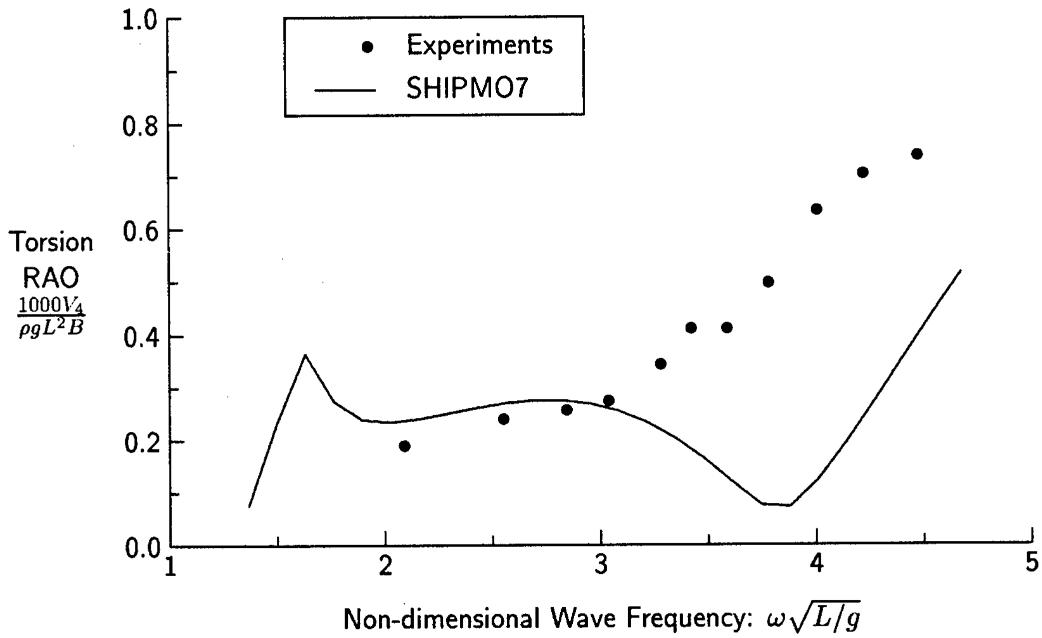

Figure 33: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 110 degrees

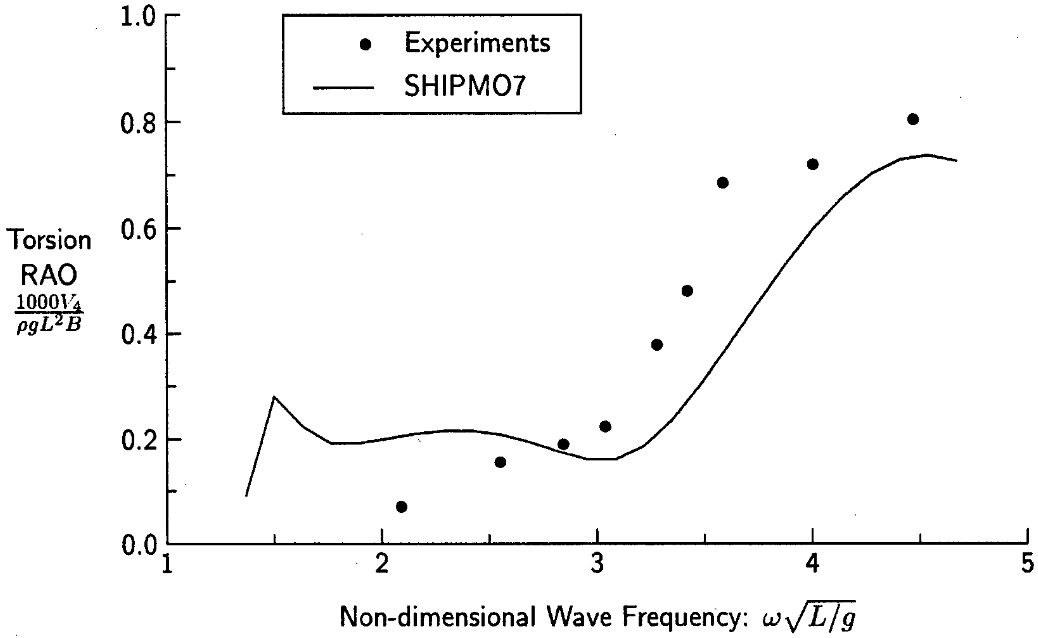

Figure 34: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 130 degrees

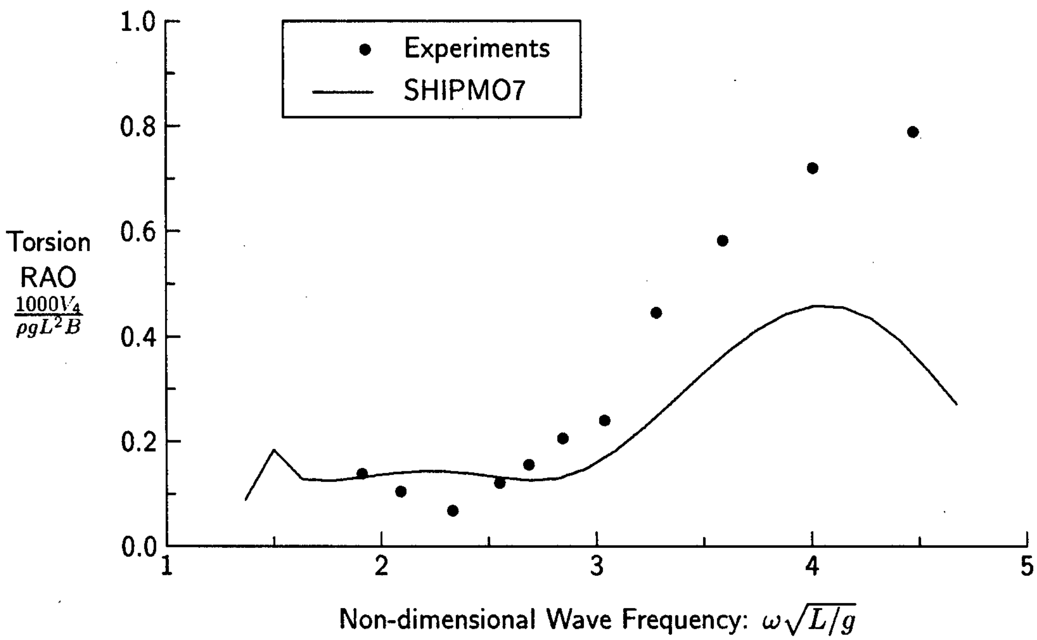

Figure 35: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 150 degrees

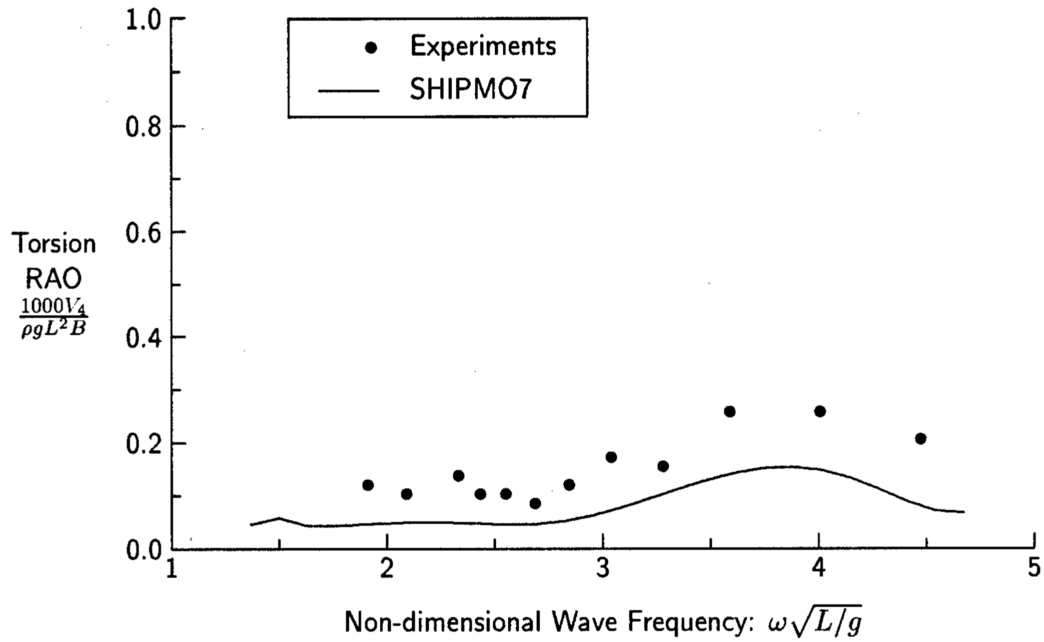

Figure 36: Torsion for Series 60, $C_B = 0.80$, $Fn = 0.15$, Heading = 170 degrees

11 Analysis of Errors for Predicted Motions and Sea Loads in Irregular Head Seas

The CPF hydroelastic model tests were conducted in response to a requirement for design sea load values. Numerical codes such as SHIPMO7 and PRECAL can also provide design sea load values, subject to the limitations of the codes. This section provides an analysis of the ratios of predicted to experimental values for ship motions and sea loads. The current analysis is limited to irregular head seas and Bretschneider spectra. The loads under consideration are vertical shear at Station 5 and vertical bending moment at midships, which is typically the most important design load.

Tables 6 to 9 give statistics for the ratios of predicted to experimental motions and loads. In the tables, m denotes the mean value while σ denotes the standard deviation. The standard deviations of the ratios are small, indicating that the ratio of predicted to experimental values exhibits relatively little scatter for each motion or load. The remaining discussion here will focus on general trends for the mean values.

Table 6: Statistics of Ratios of Predicted to Experimental Heave in Irregular Head Seas, Bretschneider Spectra

Froude Number	H_s (m)	$\zeta_3(SHIPMO)/\zeta_3(exp)$ m	σ	$\zeta_3(PRECAL)/\zeta_3(exp)$ m	σ
0.06	4, 5, 6	0.90	0.04	0.93	0.02
0.12	4, 5, 6	0.92	0.01	0.97	0.03
0.20	4, 5, 6	0.94	0.02	1.01	0.03
0.25	4, 5, 6	0.96	0.02	1.04	0.01
0.06, 0.12, 0.20, 0.25	4	0.91	0.04	0.99	0.05
0.06, 0.12, 0.20, 0.25	5	0.93	0.03	0.99	0.05
0.06, 0.12, 0.20, 0.25	6	0.95	0.02	0.98	0.04
0.06, 0.12, 0.20, 0.25	4, 5, 6	0.93	0.03	0.99	0.05

The heave ratios in Table 6 indicate SHIPMO7 slightly underpredicts heave motion while PRECAL predictions are almost identical to experimental results. For pitch, both SHIPMO7 and PRECAL predictions are virtually identical to the experiments.

As expected, discrepancies are greater for sea loads than for motions. Table 8 indicates that SHIPMO7 overpredicts midships bending moment by an average of 25 percent while PRECAL overpredicts by 9 percent on average. The SHIPMO7 overprediction shows little variation with speed. PRECAL is very accurate at low speed but deteriorates at high speed due to the zero speed Green function approximation and neglect of the steady speed diffraction potential. The degree of overprediction increases with wave height for both codes, suggesting that nonlinearities associated with wave height tend to reduce nondimensional midships bending moment.

Table 7: Statistics of Ratios of Predicted to Experimental Pitch in Irregular Head Seas, Bretschneider Spectra

Froude Number	H_s (m)	$\zeta_5(SHIPMO)/\zeta_5(exp)$ m	σ	$\zeta_5(PRECAL)/\zeta_5(exp)$ m	σ
0.06	4, 5, 6	1.00	0.04	0.97	0.04
0.12	4, 5, 6	1.01	0.03	1.01	0.03
0.20	4, 5, 6	0.96	0.04	1.00	0.04
0.25	4, 5, 6	0.93	0.04	0.99	0.04
0.06, 0.12, 0.20, 0.25	4	0.93	0.04	0.95	0.02
0.06, 0.12, 0.20, 0.25	5	0.98	0.03	0.99	0.02
0.06, 0.12, 0.20, 0.25	6	1.02	0.02	1.04	0.01
0.06, 0.12, 0.20, 0.25	4, 5, 6	0.98	0.05	0.99	0.04

Table 8: Statistics of Ratios of Predicted to Experimental Midships Vertical Bending Moment in Irregular Head Seas, Bretschneider Spectra

Froude Number	H_s (m)	$V_5(SHIPMO)/V_5(exp)$ m	σ	$V_5(PRECAL)/V_5(exp)$ m	σ
0.06	4, 5, 6	1.24	0.05	1.03	0.06
0.12	4, 5, 6	1.23	0.03	1.05	0.02
0.20	4, 5, 6	1.26	0.04	1.12	0.02
0.25	4, 5, 6	1.27	0.06	1.15	0.04
0.06, 0.12, 0.20, 0.25	4	1.19	0.01	1.04	0.05
0.06, 0.12, 0.20, 0.25	5	1.26	0.02	1.10	0.05
0.06, 0.12, 0.20, 0.25	6	1.30	0.03	1.13	0.04
0.06, 0.12, 0.20, 0.25	4, 5, 6	1.25	0.05	1.09	0.06

Table 9: Statistics of Ratios of Predicted to Experimental Vertical Shear at Station 5 in Irregular Head Seas, Bretschneider Spectra

Froude Number	H_s (m)	$V_3(SHIPMO)/V_3(exp)$ m	σ	$V_3(PRECAL)/V_3(exp)$ m	σ
0.06	4, 5, 6	1.20	0.05	0.96	0.04
0.12	4, 5, 6	1.19	0.03	0.89	0.03
0.20	4, 5, 6	1.22	0.05	0.81	0.03
0.25	4, 5, 6	1.25	0.07	0.75	0.04
0.06, 0.12, 0.20, 0.25	4	1.15	0.01	0.81	0.08
0.06, 0.12, 0.20, 0.25	5	1.23	0.03	0.86	0.08
0.06, 0.12, 0.20, 0.25	6	1.27	0.03	0.89	0.08
0.06, 0.12, 0.20, 0.25	4, 5, 6	1.22	0.06	0.85	0.09

Table 9 shows that SHIPMO7 overpredicts vertical shear at Station 5 by an average of 22 percent while PRECAL underpredicts vertical shear by an average of 15 percent. The SHIPMO7 overprediction shows little sensitivity to speed. PRECAL results deteriorate as speed increases, as occurs for bending moment. Variations with wave height suggest that nonlinear effects give reductions in nondimensional loads as wave height increases.

In summary, both SHIPMO7 and PRECAL give excellent predictions of heave and pitch in irregular head seas. SHIPMO7 consistently overpredicts vertical bending moment at midships and vertical shear at Station 5 by approximately 25 percent. PRECAL gives excellent predictions of vertical plane loads at low Froude numbers, but overpredicts bending moment at midships by 15 percent and underpredicts vertical shear at Station 5 by 25 percent as Froude number increases to 0.25.

12 Sensitivity of Sea Loads in Head Seas to Loading Condition

The sensitivity of sea loads to ship loading condition is of great practical concern. If sea loads were relatively insensitive to ship loading condition, then loads for a single loading condition could be considered representative of values for all loading conditions. Alternatively, high sensitivity of loads to loading condition would require separate evaluation of motions and loads for each loading condition.

Figures 37 to 42 compare measurements of vertical bending moment and vertical shear in irregular head seas for the deep departure condition with predictions based on measured regular seas RAOs for the deep departure and operational light conditions. In all cases, the plotted loads show a surprisingly degree of consistency. In the deep departure condition, RMS loads based on regular wave RAOs are essentially the same as loads from irregular wave tests. Furthermore, loads for the deep departure condition are approximately equal to those for the operational light condition, suggesting that a single operational condition can be used to generate representative sea loads for all loading conditions.

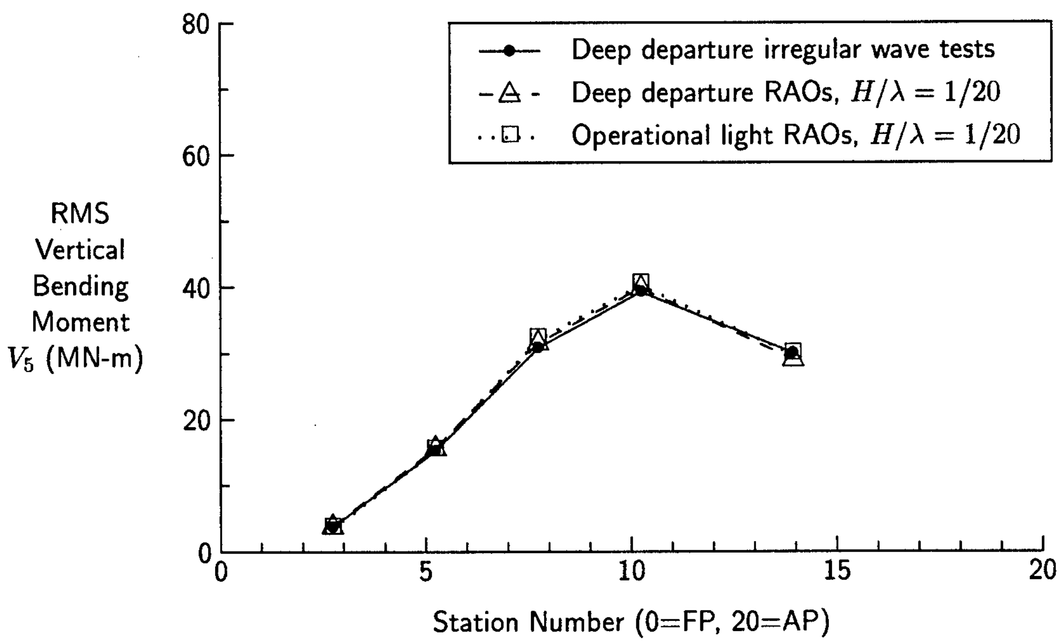

Figure 37: Vertical Bending Moment in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.06$

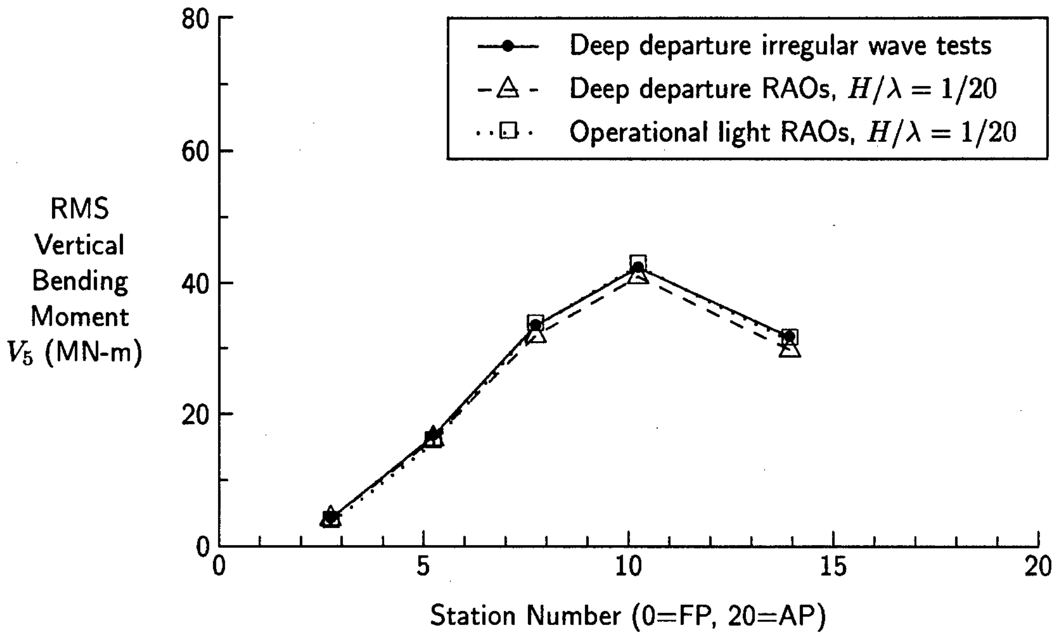

Figure 38: Vertical Bending Moment in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.12$

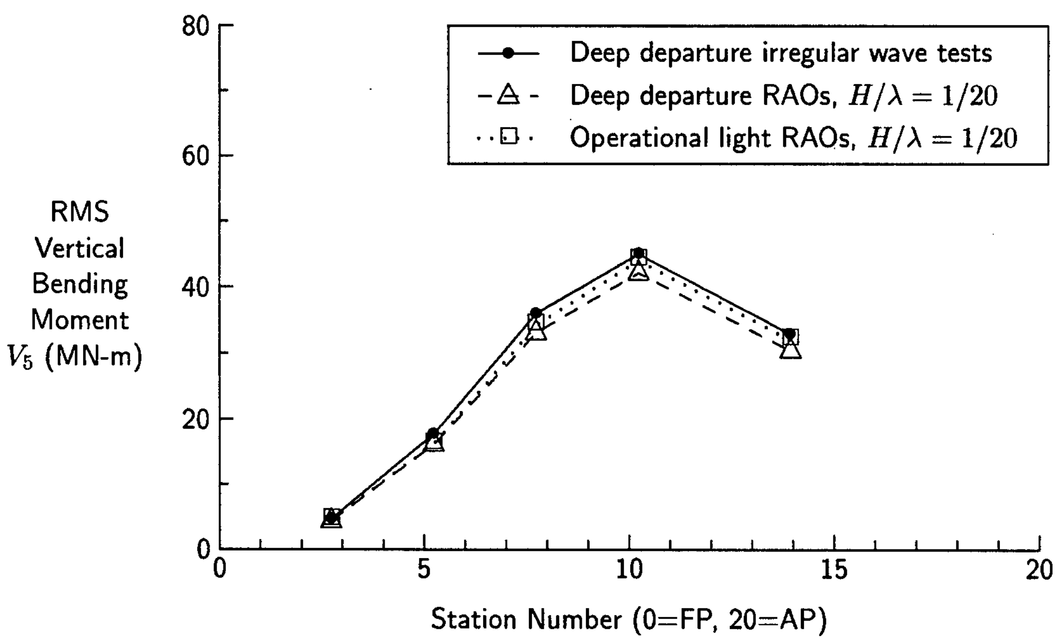

Figure 39: Vertical Bending Moment in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.20$

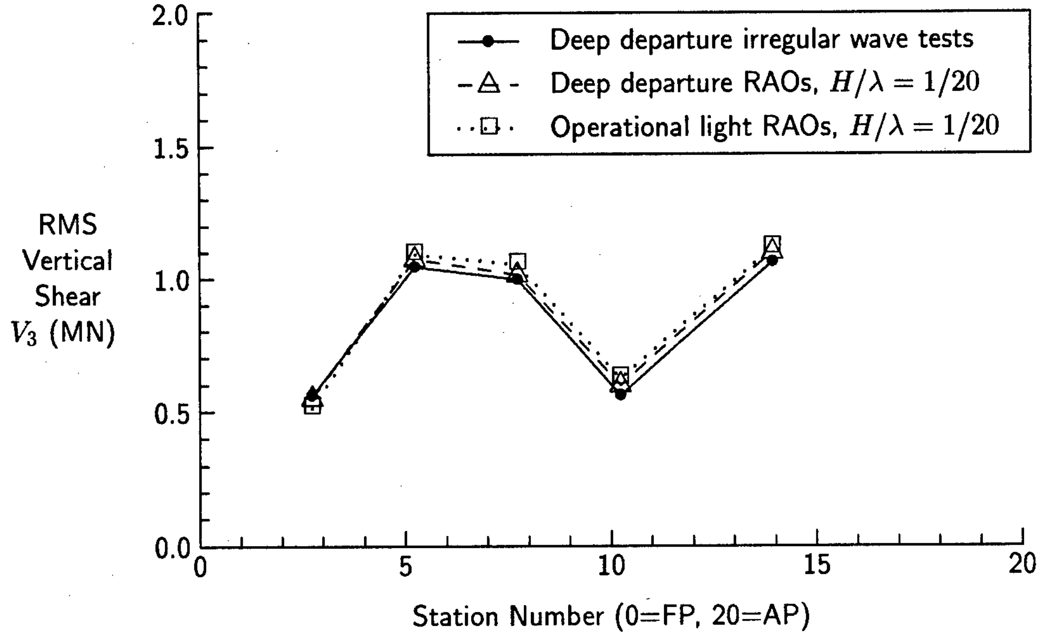

Figure 40: Vertical Shear in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.06$

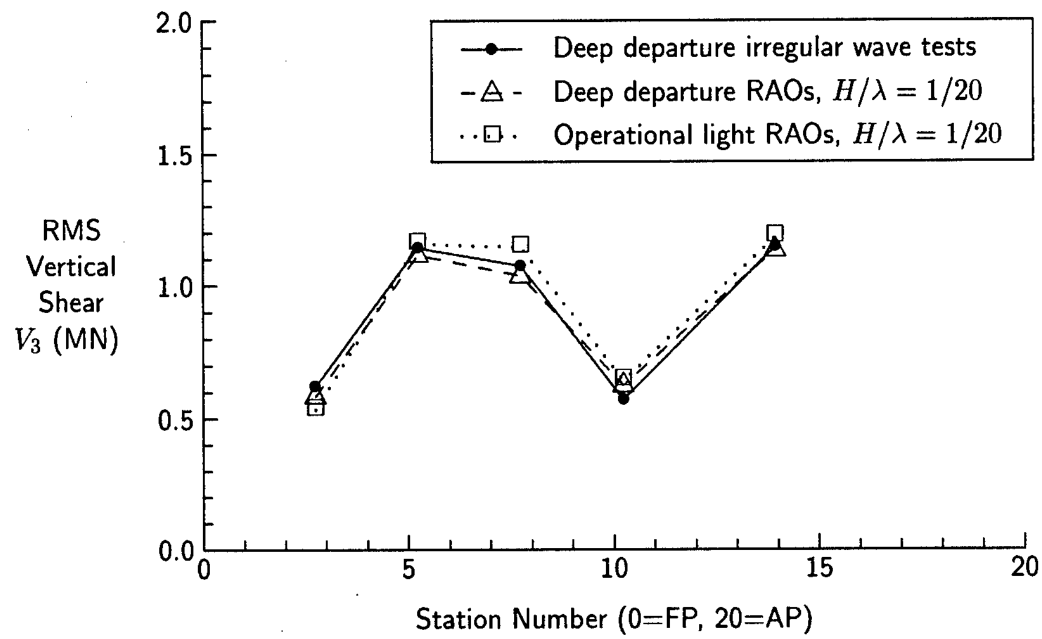

Figure 41: Vertical Shear in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.12$

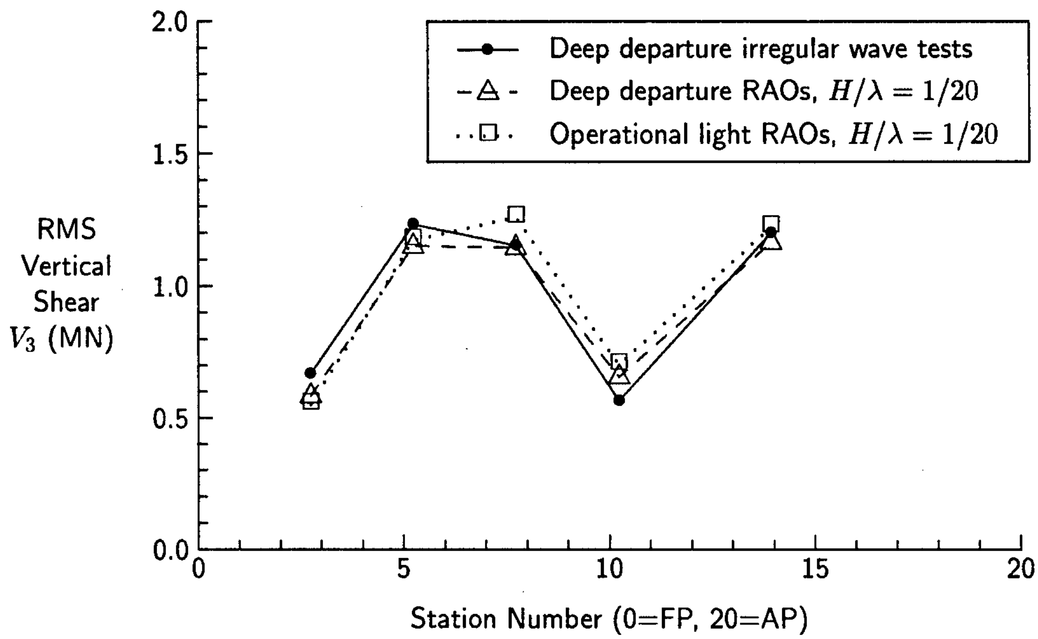

Figure 42: Vertical Shear in Irregular Head Seas for Deep Departure and Operational Light Conditions, Bretschneider Spectrum, $H_s = 5$ m, $T_p = 11$ s, $Fn = 0.20$

13 Conclusions

Both SHIPMO7 and PRECAL give generally good agreement with motions and sea loads for the CPF hydroelastic model. In contrast, MOSOLV gives generally poor agreement with experimental results.

The three-dimensional capability of PRECAL leads to vertical plane load predictions which are better than the strip theory program SHIPMO7. At high speeds, PRECAL results deteriorate somewhat because the code neglects the steady speed diffraction potential and the current study uses the PRECAL zero speed Green function approximation.

The only major discrepancies between experiments and predictions occur for torsion. The PRECAL torsion predictions assume constant metacentric height along the length of the ship, which introduces major errors. Although SHIPMO7 correctly considers the longitudinal variation of sectional metacentric height, its limited accuracy for the CPF is likely due to limitations of strip theory. The better torsion results for a more slender warship model support this conclusion.

In irregular head seas, SHIPMO7 overpredicts vertical bending moment at midships by approximately 25 percent. By comparison, PRECAL typically gives modest overpredictions between 3 and 15 percent, increasing with ship speed. The degree of overprediction for both SHIPMO7 and PRECAL increases modestly with wave height.

Vertical shear and vertical moments in head seas exhibit little variation between operational light and deep departure loading conditions; thus, a single representative loading condition can be used to determine design loads for all loading conditions.

A SHIPMO7 Sample Input File

```
CPF Hydroelastic Model, Deep Departure Condition, 1/30 wave steepness
METRIC METRIC FRESH NOSPEEDCOR NOSWELLCOR MODAMP OUTPPR  <----- Control flags
regdeepd.ppr                          <----- Post-processing file name
LOAD   NORAW                          <----- Additional computation flags
2.0 5.0 0.1                           <----- Wave frequencies
READHY  BOUND2D  LATLONG  HVCOR       <----- Hydrodynamic options
cpfdeepd.hy                           <----- Hydrodynamic coefficient file
1.0 25.0 1.0                          <----- Encounter frequencies
REGULAR                               <----- Wave spectrum
3 0.0                  <----- # of sea directions, spread angle
135 165 180                           <----- Sea direction(s) (headings)
1                <----- Number of seaways
0.0333                                <----- Wave steepness
4  0.917 1.834 3.041 3.801            <----- # of ship speeds, ship speeds
6.225  0.3247 1.440                   <----- Ship length, KG, pitch gyradius
GMINPUT  WETROLLRG                    <----- GM and roll gyradius control flags
0.0541                                <----- Metacentric height
0.319                                 <----- Wet roll gyradius
OFFSETS                               <----- Hull definition flag
21 21 0.00005 0.00005                 <----- # of stations, scaling factors
0                                     <----- Offset data
12
   0  110  318  579  897 1000 1281  1757  2000  2361  3000  3615
4630 5000 6000 7000 8000 8288 9000 10000 10431 11000 11911 12725
1
20
  0  290  515  735  974 1000 1255 1586 1975 2000 2424 2938 3000  3534  3892  4000
4231  4951  5000  5398
126 1000 2000 3000 4000 4100 5000 6000 7000 7060 8000 9000 9112 10000 10530 10680
11000 12000 12068 12621
2
21
0  721 1000 1166 1552 1930 2000 2334 2774 3000 3256 3785 4000 4376 5000  5077  5160
5711  6000  6328  6590
0 1000 1608 2000 3000 4000 4179 5000 6000 6481 7000 8000 8379 9000 9900 10000 10105
11000 11468 12000 12426
3
22
0 1000 1160 1837 2000 2390 2913 3000 3426 3932 4000 4437 4984 5000 5624 6000 6160
6294  6782  7000  7270  7338
0  800 1000 2000 2280 3000 4000 4168 5000 6000 6136 7000 8000 8027 9000 9518 9724
10000 11000 11447 12000 12140
4
21
0 1000 1665 2000 2588 3000 3306 3916 4000 4446 4930 5000 5404 5926 6000 6561 6848
7000  7073  7442  7764
0  473 1000 1324 2000 2551 3000 4000 4150 5000 6000 6149 7000 8000 8128 9000 9390
9802 10000 11000 11871
5
```

21
0 1000 2000 2268 3000 3470 4000 4273 4869 5000 5330 5731 6000 6137 6594 7000 7147
7214 7477 7773 7956
0 303 828 1000 1555 2000 2622 3000 4000 4262 5000 6000 6672 7000 8000 8753 9000
9109 10000 11000 11618
6
21
0 1000 2000 2971 3000 4000 4373 5000 5204 5702 6000 6057 6365 6688 7000 7047 7409
7435 7693 7951 8049
0 188 534 1000 1016 1679 2000 2701 3000 4000 4824 5000 6000 7000 7876 8000 8900
9000 10000 11000 11379
7
23
0 1000 2000 3000 3713 4000 4573 5000 5190 5979 6000 6360 6622 6856 6903 7000 7101
7364 7583 7632 7856 8080 8133
0 150 364 680 1000 1142 1500 1830 2000 3000 3040 4000 5000 6000 6200 6597 7000
8000 8783 9000 10000 11000 11240
8
22
0 1000 2000 3000 4000 4340 5000 5165 5754 6000 6493 6812 7000 7020 7208 7246 7396
7584 7772 7959 8147 8183
0 150 338 527 844 1000 1385 1500 2000 2261 3000 4000 4898 5000 6000 6200 7000
8000 9000 10000 11000 11191
9
20
0 1000 2000 3000 4000 4724 5000 6000 6122 6814 7000 7104 7267 7417 7567 7717 7867
8017 8167 8198
0 150 338 525 732 1000 1140 1878 2000 3000 3538 4000 5000 6000 7000 8000 9000
10000 11000 11146
10
20
0 1000 2000 3000 4000 4895 5000 6000 6348 6989 7000 7258 7398 7528 7658 7788 7918
8048 8178 8191
0 150 338 525 715 1000 1046 1668 2000 3000 3027 4000 5000 6000 7000 8000 9000
10000 11000 11101
11
20
0 1000 2000 3000 4000 4940 5000 6000 6416 7000 7043 7312 7446 7569 7693 7816 7940
8063 8186 8199
0 150 338 525 713 1000 1025 1611 2000 2899 3000 4000 5000 6000 7000 8000 9000
10000 11000 11100
12
20
0 1000 2000 3000 4000 4824 5000 6000 6348 7000 7006 7300 7446 7569 7693 7816 7940
8063 8187 8199
0 150 338 525 733 1000 1074 1674 2000 2987 3000 4000 5000 6000 7000 8000 9000
10000 11000 11100
13
21
0 1000 2000 3000 4000 4433 5000 5527 6000 6181 6895 7000 7225 7390 7519 7647 7776
7904 8033 8161 8174

```
0  150  358  589  859 1000 1225 1500 1836 2000 3000 3245 4000 5000 6000 7000 8000
9000 10000 11000 11102
14
22
0 1000 2000 3000 3437 4000 4896 5000 5777 6000 6673 6988 7000 7060 7260 7397 7533
7669 7806  7942  8079  8093
0  345  647  895 1000 1155 1500 1549 2000 2176 3000 3750 3789 4000 5000 6000 7000
8000 9000 10000 11000 11108
15
22
0 1000 1183 2000 3000 3085 4000 4787 5000 6000 6183 6668 6780 7000 7063 7221 7364
7508 7652  7796  7939  7956
0  897 1000 1281 1483 1500 1720 2000 2098 2793 3000 3750 4000 4707 5000 6000 7000
8000 9000 10000 11000 11118
16
22
  0  341  759 1000 1716 2000 3000 4000 5000 5376 6000 6216 6385 6811 7000 7012
7172 7309 7458  7606  7754  7774
517 1000 1500 1682 2000 2075 2260 2465 2803 3000 3494 3750 4000 5000 5918 6000
7000 8000 9000 10000 11000 11130
17
20
   0  178 1000 2000 3000 3293 4000 5000 5568 5892 6000 6512 6757 6911 7000 7065
7218  7372  7525  7548
1880 2000 2453 2750 2944 3000 3152 3461 3750 4000 4109 5000 6000 7000 7579 8000
9000 10000 11000 11146
18
20
   0  148 1000 2000 3000 4000 5000 5131 6000 6117 6460 6491 6618 6776 6879 6935
7000  7093  7252  7278
2970 3000 3153 3318 3488 3675 3945 4000 4677 5000 6000 6200 7000 8000 8650 9000
9411 10000 11000 11164
19
18
   0 1000 2000 3000 3871 4000 5000 5807 5913 6000 6125 6286 6447 6473 6608  6769
6930  6959
3670 3739 3811 3894 4000 4020 4286 5000 5220 5461 6000 7000 8000 8160 9000 10000
11000 11184
20
14
   0 2000 3500 5000 5434 5549 5630 5767 5924 6000 6081 6237  6394  6493
4630 4630 4630 4630 5000 5220 5500 6000 7000 7486 8000 9000 10000 10632
DISP                            <----- Control flag for load waterline
0.5803  3.189                   <----- Ship displacement, LCG from FP
5                               <----- Number of stations for load calcs
2.5  5.0  7.5  10.0  13.7       <----- Stations for load calcs
0.0039 0.0082 0.0102 0.0273 0.0260 0.0266 0.0262
0.0370 0.0474 0.0419 0.0458 0.0380 0.0420 0.0295
0.0380 0.0534 0.0220 0.0248 0.0181 0.0092 0.0027 <----- Station weights (tons, model)
0.3720 0.3720 0.3720 0.3344 0.3344 0.3465 0.3585
0.3585 0.3143 0.3143 0.3130 0.3116 0.3116 0.3116
```

```
0.3151 0.3160 0.3160 0.3160 0.3160 0.3160 0.3160 <----- Station KG's (model-scaled)
0.1360 0.1406 0.1561 0.2560 0.2498 0.2525 0.2508
0.2979 0.3373 0.3171 0.3317 0.3020 0.3175 0.2659
0.3022 0.3581 0.2295 0.2441 0.2084 0.1489 0.1135 <----- Station roll gyradii (model)
0.0021 0.372 0.061 0.039 0.104    <----- Bow overhang data
0.0    0.0   0.0   0.0   0.0      <----- Stern overhang data
0 5.0 0.01            <----- Seakeeping position data
1                                 <----- Number of bilge keel pairs
4  14                             <----- First and last stations spanned by bilge keel
 3.84 4.5  0.196 0.200 0.04       <----- Bilge keel data (model-scaled)
 4.5  5.5  0.223 0.166 0.04
 5.5  6.5  0.253 0.139 0.04
 6.5  7.5  0.265 0.108 0.04
 7.5  8.5  0.287 0.100 0.04
 8.5  9.5  0.296 0.091 0.04
 9.5 10.5  0.303 0.086 0.04
10.5 11.5  0.305 0.085 0.04
11.5 12.5  0.301 0.085 0.04
12.5 13.5  0.294 0.087 0.04
13.5 14.47 0.277 0.093 0.04
20 0.001 0.001                    <----- Skeg data (model-scaled)
19.3 0.0 0.184 0.265 0.236 0.1055 0.0 0.0  <----- Rudder data (model-scaled)
0.0 0.0 0.0 0.0 0.0 0.0 0.0       <----- Rudder roll gains
0.0 0.0 0.0                       <----- Rudder yaw gains
4                                 <----- Number of stationary foil pairs
16.4 0.195 0.135 0.070 0.035 0.035 0.000 -105.5 1.00  <----- Shaft bracket data
16.4 0.090 0.125 0.070 0.035 0.035 0.000  -48.0 1.00         (model-scaled)
18.3 0.215 0.195 0.163 0.050 0.050 0.000 -104.5 1.00
18.3 0.030 0.170 0.170 0.050 0.050 0.000  -51.0 1.00
NOSTAB                            <----- Fin or tank stabilization
```

B PRECAL Sample Input Files

B.1 HYDMES Pre-processor Input File 1 - cpfmodel.hin

```
#
## TITLE
#
AUTOMATIC FACET GENERATION - SHIPM07/PRECAL VALIDATION STUDY, May 1997
#
## SHIP NAME
#
CPF Hydroelastic Model, Deep Departure Conditions
#
## SHIP TYPE
#
MONOHULL
#
## HYDMES OPTIONS
#
OPTION
OCAL
OINP
OOUT
OMAS
ENDOPT
#
## CONSTANTS
#
CONSTS
CDEN 1.000
CACC 9.80665
ENDCON
#
## SHIP DIMENSIONS
#
SHIPDS
SDIM 6.735  6.225  0.740  0.2485  0.0019
SGMS 16.263 0.0541
SSYM Y=0
ENDSHI
#
## MASS DISTRIBUTION DATA
#   DM       XM      YM      ZM      Ixx      Iyy      Izz
#
MASSDI
0.0021   3.1515  0.0000  0.1115  0.00001  0.00000  0.00000
0.0039   3.1125  0.0000  0.1115  0.00007  0.00000  0.00000
0.0082   2.8013  0.0000  0.1115  0.00016  0.00000  0.00000
0.0102   2.4900  0.0000  0.1115  0.00025  0.00000  0.00000
0.0273   2.1788  0.0000  0.0739  0.00179  0.00000  0.00000
0.0260   1.8675  0.0000  0.0739  0.00162  0.00000  0.00000
```

```
0.0266   1.5563  0.0000  0.0860  0.00169  0.00000  0.00000
0.0262   1.2450  0.0000  0.0980  0.00165  0.00000  0.00000
0.0370   0.9338  0.0000  0.0980  0.00328  0.00000  0.00000
0.0474   0.6225  0.0000  0.0538  0.00539  0.00000  0.00000
0.0419   0.3113  0.0000  0.0538  0.00421  0.00000  0.00000
0.0458   0.0000  0.0000  0.0525  0.00505  0.00000  0.00000
0.0380  -0.3113  0.0000  0.0511  0.00346  0.00000  0.00000
0.0420  -0.6225  0.0000  0.0511  0.00423  0.00000  0.00000
0.0295  -0.9338  0.0000  0.0511  0.00208  0.00000  0.00000
0.0380  -1.2450  0.0000  0.0546  0.00347  0.00000  0.00000
0.0534  -1.5563  0.0000  0.0555  0.00685  0.00000  0.00000
0.0220  -1.8675  0.0000  0.0555  0.00116  0.00000  0.00000
0.0248  -2.1788  0.0000  0.0555  0.00148  0.00000  0.00000
0.0181  -2.4900  0.0000  0.0555  0.00079  0.00000  0.00000
0.0092  -2.8013  0.0000  0.0555  0.00020  0.00000  0.00000
0.0027  -3.1125  0.0000  0.0555  0.00003  0.00000  0.00000
ENDMAS
#
## AUTOMATIC FACETIZATION PARAMETERS
#
AFTEND
TOTFAC
0.5 1.0 80
ENDTOT
ENDAFT
FOREND
TOTFAC
0.5 1.0 80
ENDTOT
ENDFOR
#
## END OF INPUT FILE
#
ENDFIL
```

B.2 HYDMES Pre-processor Input File 2 - cpfmodel.hul

```
CPF Hydroelastic Model, Deep Departure Conditions
6.225  0.740  21
0.0 14
0.0000 0.1000 0.1750 0.2500 0.2717 0.2775 0.2815 0.2884 0.2962 0.3000 0.3041
0.3119 0.3197 0.3247
0.2315 0.2315 0.2315 0.2316 0.2500 0.2610 0.2750 0.3000 0.3500 0.3743 0.4000
0.4500 0.5000 0.5316
0.5 18
0.0000 0.0500 0.1000 0.1500 0.1936 0.2000 0.2500 0.2904 0.2957 0.3000 0.3063
0.3143 0.3224 0.3237 0.3304 0.3385 0.3465 0.3480
0.1835 0.1870 0.1906 0.1947 0.2000 0.2010 0.2143 0.2500 0.2610 0.2731 0.3000
0.3500 0.4000 0.4080 0.4500 0.5000 0.5500 0.5592
1.0 20
```

0.0000 0.0074 0.0500 0.1000 0.1500 0.2000 0.2500 0.2566 0.3000 0.3059 0.3230
0.3246 0.3309 0.3388 0.3440 0.3468 0.3500 0.3547 0.3626 0.3639
0.1485 0.1500 0.1577 0.1659 0.1744 0.1838 0.1973 0.2000 0.2339 0.2500 0.3000
0.3100 0.3500 0.4000 0.4325 0.4500 0.4706 0.5000 0.5500 0.5582
1.5 20
0.0000 0.0089 0.0500 0.1000 0.1500 0.1647 0.2000 0.2500 0.2784 0.2946 0.3000
0.3256 0.3379 0.3456 0.3500 0.3533 0.3609 0.3686 0.3763 0.3774
0.0940 0.1000 0.1227 0.1375 0.1472 0.1500 0.1576 0.1731 0.1875 0.2000 0.2055
0.2500 0.3000 0.3500 0.3790 0.4000 0.4500 0.5000 0.5500 0.5573
2.0 22
0.0000 0.0171 0.0380 0.0500 0.0858 0.1000 0.1500 0.2000 0.2500 0.2688 0.3000
0.3108 0.3193 0.3406 0.3500 0.3506 0.3586 0.3655 0.3729 0.3803 0.3877 0.3887
0.0259 0.0500 0.0750 0.0841 0.1000 0.1038 0.1130 0.1233 0.1402 0.1500 0.1747
0.1875 0.2000 0.2500 0.2959 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5565
2.5 22
0.0000 0.0500 0.0592 0.1000 0.1500 0.1543 0.2000 0.2394 0.2500 0.3000 0.3092
0.3334 0.3390 0.3500 0.3532 0.3611 0.3682 0.3754 0.3826 0.3898 0.3970 0.3978
0.0000 0.0449 0.0500 0.0641 0.0742 0.0750 0.0860 0.1000 0.1049 0.1397 0.1500
0.1875 0.2000 0.2354 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5559
3.0 22
0.0000 0.0500 0.1000 0.1500 0.1719 0.2000 0.2448 0.2500 0.2889 0.3000 0.3337
0.3494 0.3500 0.3530 0.3630 0.3699 0.3767 0.3835 0.3903 0.3971 0.4040 0.4047
0.0000 0.0173 0.0324 0.0448 0.0500 0.0578 0.0750 0.0775 0.1000 0.1088 0.1500
0.1875 0.1895 0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5554
3.5 21
0.0000 0.0500 0.1000 0.1500 0.2000 0.2217 0.2500 0.2764 0.3000 0.3091 0.3448
0.3500 0.3613 0.3695 0.3760 0.3824 0.3888 0.3952 0.4017 0.4081 0.4087
0.0000 0.0075 0.0179 0.0295 0.0430 0.0500 0.0613 0.0750 0.0918 0.1000 0.1500
0.1623 0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5551
4.0 20
0.0000 0.0500 0.1000 0.1500 0.2000 0.2412 0.2500 0.3000 0.3174 0.3500 0.3503
0.3650 0.3723 0.3785 0.3847 0.3908 0.3970 0.4032 0.4094 0.4100
0.0000 0.0075 0.0169 0.0263 0.0367 0.0500 0.0537 0.0837 0.1000 0.1494 0.1500
0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5550
4.5 20
0.0000 0.0500 0.1000 0.1500 0.2000 0.2470 0.2500 0.3000 0.3208 0.3500 0.3522
0.3656 0.3723 0.3785 0.3847 0.3908 0.3970 0.4032 0.4093 0.4100
0.0000 0.0075 0.0169 0.0263 0.0357 0.0500 0.0513 0.0806 0.1000 0.1450 0.1500
0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5550
5.0 20
0.0000 0.0500 0.1000 0.1500 0.2000 0.2448 0.2500 0.3000 0.3174 0.3495 0.3500
0.3629 0.3699 0.3764 0.3829 0.3894 0.3959 0.4024 0.4089 0.4096
0.0000 0.0075 0.0169 0.0263 0.0358 0.0500 0.0523 0.0834 0.1000 0.1500 0.1514
0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5551
5.5 20
0.0000 0.0500 0.1000 0.1500 0.2000 0.2362 0.2500 0.3000 0.3061 0.3407 0.3500
0.3552 0.3634 0.3709 0.3784 0.3859 0.3934 0.4009 0.4084 0.4099
0.0000 0.0075 0.0169 0.0263 0.0366 0.0500 0.0570 0.0939 0.1000 0.1500 0.1769
0.2000 0.2500 0.3000 0.3500 0.4000 0.4500 0.5000 0.5500 0.5573
6.0 22
0.0000 0.0500 0.1000 0.1500 0.2000 0.2170 0.2500 0.2583 0.2877 0.3000 0.3247

0.3406 0.3500 0.3510 0.3604 0.3623 0.3698 0.3792 0.3886 0.3980 0.4074 0.4092
0.0000 0.0075 0.0169 0.0264 0.0422 0.0500 0.0693 0.0750 0.1000 0.1131 0.1500
0.2000 0.2449 0.2500 0.3000 0.3100 0.3500 0.4000 0.4500 0.5000 0.5500 0.5596
6.5 23
0.0000 0.0500 0.1000 0.1500 0.1857 0.2000 0.2287 0.2500 0.2595 0.2990 0.3000
0.3180 0.3311 0.3428 0.3452 0.3500 0.3551 0.3682 0.3792 0.3816 0.3928 0.4040
0.4067
0.0000 0.0075 0.0182 0.0340 0.0500 0.0571 0.0750 0.0915 0.1000 0.1500 0.1520
0.2000 0.2500 0.3000 0.3100 0.3299 0.3500 0.4000 0.4392 0.4500 0.5000 0.5500
0.5620
7.0 21
0.0000 0.0500 0.1000 0.1486 0.1500 0.2000 0.2187 0.2500 0.2602 0.2851 0.3000
0.3029 0.3183 0.3344 0.3500 0.3524 0.3705 0.3718 0.3847 0.3976 0.4025
0.0000 0.0094 0.0267 0.0500 0.0508 0.0840 0.1000 0.1351 0.1500 0.2000 0.2412
0.2500 0.3000 0.3500 0.3938 0.4000 0.4450 0.4500 0.5000 0.5500 0.5690
7.5 21
0.0000 0.0500 0.1000 0.1134 0.1500 0.1735 0.2000 0.2137 0.2435 0.2500 0.2665
0.2866 0.3000 0.3069 0.3297 0.3500 0.3574 0.3607 0.3739 0.3887 0.3978
0.0000 0.0152 0.0414 0.0500 0.0778 0.1000 0.1311 0.1500 0.2000 0.2131 0.2500
0.3000 0.3336 0.3500 0.4000 0.4377 0.4500 0.4555 0.5000 0.5500 0.5809
8.0 21
0.0000 0.0500 0.0833 0.1000 0.1294 0.1500 0.1653 0.1958 0.2000 0.2223 0.2465
0.2500 0.2702 0.2963 0.3000 0.3281 0.3424 0.3500 0.3537 0.3721 0.3882
0.0000 0.0237 0.0500 0.0662 0.1000 0.1276 0.1500 0.2000 0.2075 0.2500 0.3000
0.3075 0.3500 0.4000 0.4064 0.4500 0.4695 0.4901 0.5000 0.5500 0.5936
8.5 22
0.0000 0.0500 0.0580 0.0919 0.1000 0.1195 0.1457 0.1500 0.1713 0.1966 0.2000
0.2219 0.2492 0.2500 0.2812 0.3000 0.3080 0.3147 0.3391 0.3500 0.3635 0.3669
0.0000 0.0400 0.0500 0.1000 0.1140 0.1500 0.2000 0.2084 0.2500 0.3000 0.3068
0.3500 0.4000 0.4014 0.4500 0.4759 0.4862 0.5000 0.5500 0.5724 0.6000 0.6070
9.0 21
0.0000 0.0361 0.0500 0.0583 0.0776 0.0965 0.1000 0.1167 0.1387 0.1500 0.1628
0.1893 0.2000 0.2188 0.2500 0.2539 0.2580 0.2856 0.3000 0.3164 0.3295
0.0000 0.0500 0.0804 0.1000 0.1500 0.2000 0.2090 0.2500 0.3000 0.3241 0.3500
0.4000 0.4190 0.4500 0.4950 0.5000 0.5053 0.5500 0.5734 0.6000 0.6213
9.5 20
0.0000 0.0145 0.0258 0.0368 0.0487 0.0500 0.0628 0.0793 0.0988 0.1000 0.1212
0.1469 0.1500 0.1767 0.1946 0.2000 0.2116 0.2476 0.2500 0.2699
0.0063 0.0500 0.1000 0.1500 0.2000 0.2050 0.2500 0.3000 0.3500 0.3530 0.4000
0.4500 0.4556 0.5000 0.5265 0.5340 0.5500 0.6000 0.6034 0.6311
10.0 14
0.0000 0.0015 0.0030 0.0055 0.0159 0.0290 0.0449 0.0500 0.0641 0.0879 0.1000
0.1181 0.1500 0.1808
0.2315 0.2365 0.2416 0.2500 0.3000 0.3500 0.4000 0.4144 0.4500 0.5000 0.5216
0.5500 0.5956 0.6363

B.3 HYDCAL Input File - cpfmodel.cnd

```
## TITLE
HYDCAL RUN AT FR = 0.06,  HEADING = 135 (May 1997)
## SHIP NAME
CPF Hydroelastic Model, Deep Departure Conditions
## SHIP TYPE
MONOHULL
## HYDCAL OPTIONS
OPTION
OKTS
OFSP
ENDOPT
## OPERATING CONDITIONS
CONDNS
SPED  0.917
HEAD  135.0
FREQ  2.00 2.10 2.20 2.30 2.40
      2.50 2.60 2.70 2.80 2.90
      3.00 3.10 3.20 3.30 3.40
      3.50 3.60 3.70 3.80 3.90
      4.00 4.10 4.20 4.30 4.40
ENDCON
## FREE-SURFACE PANEL INFORMATION
FSPANS
2
ENDFSP
ENDFIL
```

B.4 RESCAL Input File - cpfmodel.inp

```
## TITLE
RESCAL RUN AT FN=0.06, HEAD = 135, DAMPING = 0.135 FROM SHIPM07 (June 1996)
## SHIP NAME
CPF Hydroelastic Model, Deep Departure Conditions
## SHIP TYPE
MONOHULL
## RESCAL OPTIONS
OPTION
OMOT
OPRE
OLOA
ENDOPT
## ROLL DAMPING INPUT
ROLLIN
DAMP 0.135
ENDROL
## LOAD POSITION - Long. loads are calculated at SHIPM07 stations 2.5, 5.0,
#                  7.5, 10.0, 13.7 (PRECAL convention - 0.0 at AP, 1.0 at FP)
LOPOSN
LONGI
0.875
0.750
0.625
0.500
0.315
ENDLOP
## END OF INPUT FILE
ENDFIL
```

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Validation of SHIPMO7 and PRECAL with the CPF Hydroelastic Model

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

McTAGGART, Kevin A. and CHOW, Dann L.

5. DATE OF PUBLICATION (Month and year of publication of document.) August 1997	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.) 61	6b. NO. OF REFS. (Total cited in document.) 22

6. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

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This report gives results of an extensive validation of DND's strip theory program SHIPMO7 and the three-dimensional ship motion code PRECAL developed by Cooperative Research Ships. Ship motion and sea load predictions are compared with results for the CPF hydroelastic model, which was tested in regular and irregular waves in both head and oblique seas. In general, both codes give excellent agreement for ship motions and reasonable agreement for sea loads. In irregular head seas, PRECAL overpredicts vertical bending moment at midships by an average of 9 percent, which is superior to the average overprediction by SHIPMO7 of 25 percent.

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